Assessment of the Walleye Pollock Stock in the Gulf of Alaska

by

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Summary of major changes

Relative to last year's assessment, the following changes have been in the current assessment.

New Input data:

1. Fishery: 2000 catch at age.

2. Shelikof Strait EIT survey: 2000 age composition, 2001 biomass and age composition.

3. NMFS bottom trawl survey: 2001 biomass and length composition

4. ADF&G crab/groundfish trawl survey: 2000 age composition, 2001 biomass and length composition.

5. Estimates of pollock biomass during 1961-82 from a GLM model using historical 400-mesh eastern trawl survey data.

Assessment model

The age-structured assessment model developed using ADModel Builder (a C++ software language extension and automatic differentiation library) used for assessments in 1999 and 2000 is unchanged except for a few details. Model exploration focused on approaches to incorporating trawl survey data prior to 1984 and modeling information from a comparative trawling experiment between an ADFG 400-mesh eastern trawl and a NMFS poly-Nor'eastern trawl (von Szalay and Brown in press).

Assessment results

Estimated spawning biomass in 2002 is 158,300 t, a decrease of 22% from last year's estimate for 2001, and a decrease of 8% from last year's projection for 2002. Spawning biomass in 2002 is estimated to be 26% of unfished. Lower model estimates of biomass in 2002 are primarily due to lower than expected biomass from the 2001 NMFS trawl survey (65% percent decrease from the 1999 survey) and low abundance of spawning adults in the 2001 Shelikof Strait EIT survey (49% decrease from the 2000 survey). The 2002 ABC recommendation for pollock in the Gulf of Alaska west of 140° W long. is 53,490 t, a decrease of 34% from the last year's projected maximum permissible ABC for 2002. The recommendation is lower in part because of lower than projected biomass (21%), and in part because of a more conservative ABC recommendation (13%).

For pollock in southeast Alaska (East Yakutat and Southeastern areas) the ABC recommendation is unchanged at 6,460 t.

Introduction

Walleye pollock (*Theragra chalcogramma*) is a semi-pelagic schooling fish widely distributed in the North Pacific Ocean. Pollock in the Gulf of Alaska are managed as a single stock independently of pollock in the Bering Sea and Aleutian Islands. The separation of pollock in Alaskan waters into eastern Bering Sea and Gulf of Alaska stocks is supported by analysis of larval drift patterns from spawning locations (Bailey et al. 1997), genetic studies of allozyme frequencies (Grant and Utter 1980), mtDNA variability (Mulligan et al. 1992), and microsatellite allele variability (Bailey et al. 1997). Investigations of stock structure within the Gulf of Alaska are in progress by the Alaska Fisheries Science Center and ADF&G.

Fishery

The commercial fishery for walleye pollock in the Gulf of Alaska started as a foreign fishery in the early 1970s (Megrey 1989). Catches increased rapidly during the late 1970s and early 1980s (Table 1.1). Large spawning aggregations were discovered in Shelikof Strait in 1981, and a fishery developed for which pollock roe was an important product. The domestic fishery for pollock developed rapidly in the Gulf of Alaska with only a short period of joint venture operations in the mid-1980s. The fishery was fully domestic by 1988.

The fishery for pollock in the Gulf of Alaska is entirely shore-based with approximately 90% of the catch taken using pelagic trawls. During winter, fishing effort is targeted primarily on pre-spawning aggregations in Shelikof Strait and near the Shumagin Islands (Fig. 1.1). Fishing areas in summer are less predictable, but typically fishing occurs on the east side of Kodiak Island and in nearshore waters along the Alaska Peninsula. The August 7, 2000, court order banning trawling inside Steller sea lion critical habitat moved fishing effort further offshore in the C and D seasons (Fig. 1.2), and prevented the TAC from being taken due to the lack fishable concentrations of pollock outside critical habitat, particularly in Chirikof management area.

Kodiak is the major port for pollock in the Gulf of Alaska, with 53% of the 1995-2000 landings. Sand Point and Dutch Harbor are also important ports, sharing 35% of 1995-2000 landings. Secondary ports, including Cordova, Kenai, King Cove, and Port Moller, account for the remaining 12% of the 1995-2000 landings.

Since 1992, the Gulf of Alaska pollock TAC has been apportioned spatially and temporally to reduce impacts on Steller sea lions. Although the details of the apportionment scheme have evolved over time, the general objective is to allocate the TAC to management areas based on the distribution of surveyed biomass, and to establish three or four seasons between mid-January and autumn during which some fraction of the TAC can be taken.

Data Used in the Assessment

The data used in the assessment model consist of estimates of annual catch in tons, fishery age composition, NMFS summer bottom trawl survey estimates of biomass and age composition, echo integration trawl (EIT) survey estimates of biomass and age composition in Shelikof Strait, egg production estimates of spawning biomass in Shelikof Strait, and ADF&G bottom trawl survey estimates of biomass and length and age composition. Length composition data are used when age composition estimates were unavailable, such as the fishery in the early part of the modeled time period.

Total Catch

Estimated catch was derived by the NMFS Regional Office from a blend of weekly processor reports and observer at-sea discard estimates (Table 1.2). Catches include the state-managed pollock fishery in Prince William Sound. In 1996-2001, the pollock Guideline Harvest Level (GHL) for the PWS fishery was deducted from the Total Allowable Catch (TAC) recommended by North Pacific Management Council (NPFMC).

Fishery Age Composition

Estimates of fishery age composition were derived from at-sea and port sampling of the pollock catch for length and ageing structures (otoliths). Pollock otoliths collected during the 2000 fishery were aged using the revised criteria described in Hollowed et al. (1995). Catch age composition was estimated using methods described by Kimura and Chikuni (1989). Age samples were used to construct age-length keys by sex and stratum. These keys were applied to length frequency data to obtain stratum-specific age composition estimates, which were then weighted by the catch in numbers in each stratum to obtain an overall age composition. Age and length samples from the 2000 fishery were stratified by trimester and statistical area as follows:

Time strata		Shumagin-610	Chirikof-620	Kodiak-630	PWS-649
1st trimester (Jan-Apr)	No. ages	233	305	563	123
	No. lengths	2750	3906	8580	598
2nd trimester (May-Aug)	No. ages	224	----	230	----
	No. lengths	1335	----	2571	----
3rd trimester (Sep-Dec)	No. ages	222	----	188	----
	No. lengths	2861	----	2747	----

The lack of samples (and fishing) in the Chirikof area in the 2nd and 3rd trimesters was a result of the August 7, 2000, court order banning trawling inside critical habitat. The 1994 and 1995 year classes (ages 5 and 6) were abundant in nearly all strata in 2000 (Fig. 1.3). Mean age increased from the Kodiak area (6.0 yrs) to the Shumagin area (6.9 yrs), suggesting greater dispersal of older fish to the west. Age composition from samples of the PWS pollock fishery was similar to the overall age composition outside PWS in the 1st trimester, except for stronger representation of the 1994 year class (age 6) (Fig. 1.4).

Fishery catch at age in 1976-2000 is presented in Table 1.3 (See also Fig. 1.5). Sample sizes for ages and lengths are given in Table 1.4.

Gulf of Alaska Bottom Trawl Survey

Trawl surveys have been conducted by Alaska Fisheries Science Center (AFSC) every three years (beginning in 1984) to assess the abundance of groundfish in the Gulf of Alaska (Table 1.5). Starting in 2001, the survey frequency was increased to every two years. The survey uses a stratified random design, with 49 strata based on depth, habitat, and management area (Martin 1997). Area-swept biomass estimates are obtained using mean CPUE (standardized for trawling distance and mean net width) and stratum area. The survey is conducted from chartered commercial bottom trawlers using standardized poly-Nor'eastern high opening bottom trawls rigged with roller gear. Surveying effort averages 750 tows, 75% of which contain pollock (Table 1.6).

The time series of pollock biomass used in the assessment model is based on the surveyed area in the Gulf of Alaska west of 140° W long, obtained by adding the biomass estimates for the Shumagin, Chirikof, Kodiak INPFC areas, and the western portion of Yakutat INPFC area. Biomass estimates for 1990, 1993, 1996, and 1999 for the west Yakutat region were obtained by splitting strata and survey CPUE data at 140° W long. (M. Martin, AFSC, Seattle, WA, pers. comm. 1998). For surveys in 1984 and 1987, the average adjustment for West Yakutat in the 1990-99 surveys was applied (2.7% increase). The average adjustment was also used in 2001, when West Yakutat was not surveyed.

An adjustment was also made to the survey times series to account for unsurveyed pollock in Prince William Sound. This adjustment was derived from an area-swept biomass estimate for PWS from a trawl survey conducted by ADF&G in 1999, using a standard ADF&G 400 mesh eastern trawl. The 1999 biomass estimate for PWS was 6,304 t ± 2,812 t (95% CI) (W. Bechtol, ADF&G, 1999, pers. comm.). The PWS biomass estimate should be considered a minimum estimate because ADF&G survey gear is less effective at catching pollock compared to the triennial survey gear (von Szalay and Brown, in press). For 1999, the biomass estimates for the triennial survey and the PWS survey were simply added to obtain a total biomass estimate. The adjustment factor for the 1999 survey, (PWS + Triennial)/Triennial, was applied to other triennial surveys, and increased biomass by 1.05%. We consider this an interim approach to assessing PWS pollock, and anticipate improvements from increased surveying effort in PWS and additional comparative work.

The Alaska Fisheries Science Center conducted its seventh comprehensive bottom trawl survey of the Gulf of Alaska during the summer of 2001. The 2001 survey extended east to 147° W long. and covered only the Western and Central Gulf of Alaska (Shumagin, Chirikof, and Kodiak INPFC areas). Since 97% of the pollock biomass is in this area on average , the truncated survey area does not seriously compromise the survey's ability to assess pollock west of 140° W long. A total of 489 successful tows by two chartered commercial bottom trawlers were achieved throughout the survey area. The 2001 biomass estimate of pollock in the surveyed area was 208,542 t (95% confidence interval (CI): 80,110 t - 336,973 t) (Table 1.7) .

The 2001 estimate of pollock biomass west of 140° W long is 216,761 t, a 65% decline from the 1999 survey estimate (Table 1.5). Previous assessment authors commented on the stability of pollock biomass from the NMFS bottom trawl survey, which showed a mean percent change of about 9% between surveys three years apart. Obviously, such comments cannot be applied to the 2001 survey results. A large and only partly anticipated decline in biomass for the NMFS bottom trawl survey (Predicted survey biomass based on last year's assessment model was 300,100 t) is of particular concern because the biomass trend and the assumption of full catchability for this survey are critical to assessment of pollock in the GOA.

Length frequencies by INPFC statistical area from the 2001 survey were dominated by juvenile pollock (Fig. 1.6). In the Shumagin and the Kodiak INPFC areas, age-1 fish were most abundant, while in the Chirikof INPFC area, the length distribution shows strong modes of both age-1 and age-2 fish. Adults were common in the length samples only in the Shumagin INPFC area. The spatial distribution of pollock CPUE was similar to previous surveys, with the highest CPUE in nearshore areas along the Alaska Peninsula, in the Shelikof sea valley, and on the east side of Kodiak Island, only with lower mean CPUE than previous surveys (Fig. 1.7). Although the abundance of adults is very low in the 2001 survey, the abundance of juveniles in the 10-30 cm range (age-1and age-2 fish) was the highest in the survey time series, suggesting that incoming year classes may be above average.

Bottom Trawl Age Composition
Estimates of numbers at age from the bottom trawl survey were obtained from length-stratified otolith samples and length frequency samples (Table 1.8). Numbers at age were estimated for three strata: Western GOA (Shumagin INPFC area), Central GOA (Chirikof and Kodiak INPFC areas), Eastern GOA (Yakutat and Southeastern INPFC areas) using age-length keys and CPUE-weighted length frequency data. The combined Western and Central age composition was used in the assessment model.

Shelikof Strait Echo Integration Trawl Survey

Echo integration trawl surveys to assess the biomass of pollock in the Shelikof Strait area have been conducted annually since 1981 (except 1982 and 1999). Survey methods and results for 2001 are presented in an Appendix to the SAFE (Guttormsen et al. 2001). The 2001 biomass estimate for age 2+ pollock in Shelikof Strait was 369,600 t, a increase of 10% from the 2000 biomass (Table 1.5). Although total biomass shows little change from 2000 to 2001, only 34% of the biomass in 2001 was greater than 35 cm in length (> age 3), indicating an unexpected scarcity of spawning adults in Shelikof Strait (Fig. 1.8). In contrast, the estimated abundance of age-2 fish (3.6 billion) was the largest in the Shelikof Strait EIT time series, suggesting that the 1999 year class is relatively strong.

Since the assessment model only includes individuals age 2 and older, the biomass of age-1 fish in the 1995 and 2000 surveys was subtracted from the total biomass for those years (reducing the biomass by 15% and 14% respectively (Table 1.5). In all other surveys the biomass of age-1 fish was less than 2% of the total biomass.

Echo Integrated Trawl Survey Length Frequency
Annual biomass distributions by length from the Shelikof Strait EIT survey show the movement of the strong 1988 year class through the population (Fig. 1.9). In recent years, there is evidence of strong 1994 and 1999 year classes. In the 2001 survey, the length frequency is dominated by the age-2 fish from the 1999 year class.

Echo Integrated Trawl Survey Age Composition
Estimates of numbers at age from the Shelikof Strait EIT survey (1981 - 1991, 1994 -1998, 2000, 2001 (Table 1.8)) were used in the assessment model. Otoliths collected during the 1994 - 1998 EIT surveys were aged using the revised criteria described in Hollowed et al. (1995). Sample sizes for ages and lengths are given Table 1.6.

Egg Production Estimates of Spawning Biomass

Estimates of spawning biomass in Shelikof Strait derived from egg production methods were included in the assessment model. A complete description of the estimation process is given in Picquelle and Megrey (1993). The estimates of spawning biomass in Shelikof Strait show a pattern similar to the acoustic survey (Table 1.5). The annual egg production spawning biomass estimate for 1981 is questionable because of sampling deficiencies during the egg surveys for that year (Kendall and Picquelle 1990). Coefficients of variation (CV) associated with these estimates were included in the assessment model.

Alaska Department of Fish and Game Crab/Groundfish Trawl Survey

The Alaska Department of Fish and Game (ADF&G) has conducted bottom trawl surveys of nearshore areas of the Gulf of Alaska since 1987. Although these surveys are designed to monitor population trends of Tanner crab and red king crab, walleye pollock and other fish are also sampled. Standardized survey methods using a 400-mesh eastern trawl were employed from 1987 to the present. The survey is designed to sample a fixed number of stations from mostly nearshore areas from Kodiak Island to Unimak Pass, and does not cover the entire shelf area. The average number of tows completed during the survey is 360. Details of the ADF&G trawl gear and sampling procedures are in Blackburn and Pengilly (1994).

The 2001 biomass estimate for pollock for the ADF&G crab/groundfish survey was 86,967 t, a decline of 15% from the 2000 biomass estimate (Table 1.5). The ADF&G biomass trend does not show the same steep decline of adult fish in 2001 suggested by the 2001 NMFS bottom trawl survey and the 2001 Shelikof Strait EIT survey.

Researchers at AFSC are exploring other methods of integrating ADF&G crab/groundfish survey data in stock assessment. A comparative trawling experiment using the ADFG 400-mesh eastern trawl and the NMFS poly-Nor'eastern trawl produced estimates of relative catchability (von Szalay and Brown in press). One approach consists of applying the fishing power correction obtained from this experiment to the CPUE from the ADF&G survey and combining these data with NMFS survey data in years when both surveys are conducted. The NMFS trawl survey is a multipurpose survey, with lower than optimal coverage for pollock in nearshore areas that are intensively sampled during the ADF&G crab/groundfish survey. Briefly, the details of the approach are as follows. The ADF&G survey pollock CPUE is multiplied by the FPC of 3.84. New survey strata are defined so that ADF&G sampling stations are relatively uniform within these strata. For the new strata, area-swept biomass estimates are obtained using both ADF&G and NMFS survey data. Preliminary results are encouraging, and suggest that the CV of pollock biomass estimates can be reduced even when uncertainty in the FPC estimate is taken into account (von Szalay pers. comm.). An increase in pollock biomass resulted when this method was applied to surveys in 1999 (22% increase) and 2001(82% increase), suggesting that nearshore areas are not being adequately surveyed during the NMFS bottom trawl survey.

There are difficulties and unresolved issues with this approach. Since the difference in the timing of the surveys can be as large as two months, there is a potential for seasonal movement of pollock from one survey to the next. In addition, the selectivity of the two nets is likely different, so combined-data biomass estimates will have length selectivity characteristics intermediate between the gears, and will be dependent on the relative number of tows from each survey gear. Finally, since the NMFS time series begins in 1984, prior to the start of the ADF&G crab/groundfish survey, obtaining a consistent time series of biomass estimates for population modeling may not be possible.

ADF&G Survey Length Frequency
Pollock length-frequency for the ADF&G survey in 1989-2001 (excluding 1991 and 1995) typically show a primary mode at lengths greater than 45 cm (Fig. 1.10). The predominance of large fish in the ADF&G survey may result from the selectivity of the gear, or because of greater abundance of large pollock in the areas surveyed.

ADF&G Survey Age Composition
Ages were determined by age readers in the AFSC age and growth unit from an initial sample of pollock otoliths collected during the 2000 ADF&G survey (N = 559). Comparison with fishery age composition

during the 2nd trimester (May-August) shows that older fish (> age-8) are more common in the ADF&G crab/groundfish survey (Figure 1.11). This is consistent with the assessment model, which estimates a domed-shaped selectivity pattern for the fishery, but an asymptotic selectivity pattern for the ADF&G survey.

Qualitative survey trends

To qualitatively assess recent trends in survey abundance, we divided each survey time series by the average biomass for the survey since 1986 so that they could all be plotted on the same scale. The Shelikof Strait EIT survey was split into separate time series corresponding to the two acoustic systems used for the survey. Although there is considerable variability in each survey time series, a fairly clear downward trend is evident (Fig. 1.12). A lowess scatterplot smoother (SPLUS 1993) fit to the relative abundance data in aggregate shows a similar, but more gradual, decline than the estimated biomass trend from the assessment model.

McKelvey Index

McKelvey (1996) found a significant correlation between the abundance of age-1 pollock in the Shelikof Strait EIT survey and subsequent estimates of year-class strength. The McKelvey index is defined as the estimated abundance of 9-16 cm fish in the Shelikof Strait EIT survey, and is an index of recruitment at age 2 in the following year (Table 1.9). The relationship between the abundance of age-1 pollock in the Shelikof Strait EIT survey and year-class strength provides a recruitment forecast for the year following the most recent Shelikof Strait EIT survey.

2001 FOCI Year Class Prediction

Basis: This forecast is based on five data sources: three physical properties and two biological data sets. The sources are: 1) observed 2001 Kodiak monthly precipitation, 2) wind mixing energy at [57N, 156W] estimated from 2001 sea-level pressure analyses, 3) advection of ocean water in the vicinity of Shelikof Strait inferred from drogued drifters deployed during the spring of 2001, 4) rough counts of pollock larvae from a survey conducted in May 2001, and 5) estimates of age 2 pollock abundance from this years assessment.

Analysis: The winter was wet this year (Table 1) with only February's rainfall near the 30-year mean. Spring rain (except for April at 119% of the 30-year mean) was low. Thus winter and spring conditions favored larval survival and the recruitment score for rainfall is high.

Table. Kodiak precipitation for 2001

Month	*% 30-year average*
Jan	175
Feb	96
Mar	193
Apr	119
May	81
June	45

FOCI believes that Kodiak precipitation is a valid proxy for fresh-water runoff that contributes to the density contrast between coastal and Alaska Coastal Current water in Shelikof Strait. The greater the contrast, the more likely that eddies and other instabilities will form. Such secondary circulations have attributes that make them beneficial to survival of larval pollock. Based on this information, the forecast element for Kodiak rainfall has a score of 2.45. This is "strong" on the continuum from 1 (weak) to 3 (strong).

Wind mixing at the exit area of Shelikof Strait followed a similar pattern established in 1997 when the PDO changed sign. Mixing is significantly below the 30-year mean.

Table. Wind mixing at the exit of Shelikof Strait for 2001

Month	*% 30-year average*
Jan	36
Feb	31
Mar	49
Apr	49
May	54
June	27

Strong winds in winter help mix nutrients into the upper ocean layer to provide a basis for the spring phytoplankton bloom. Weak winter winds this year did not aid concentration of nutrients in the photic zone. Weak spring winds, as experienced especially during April and May, are thought to better enable first feeding pollock larvae to locate and capture food. Weak mixing in winter is not conducive to high survival rates, while weak mixing in spring favors recruitment. This mix produces an average forecast.. The wind mixing score for this year is 2.25, which equates to "average".

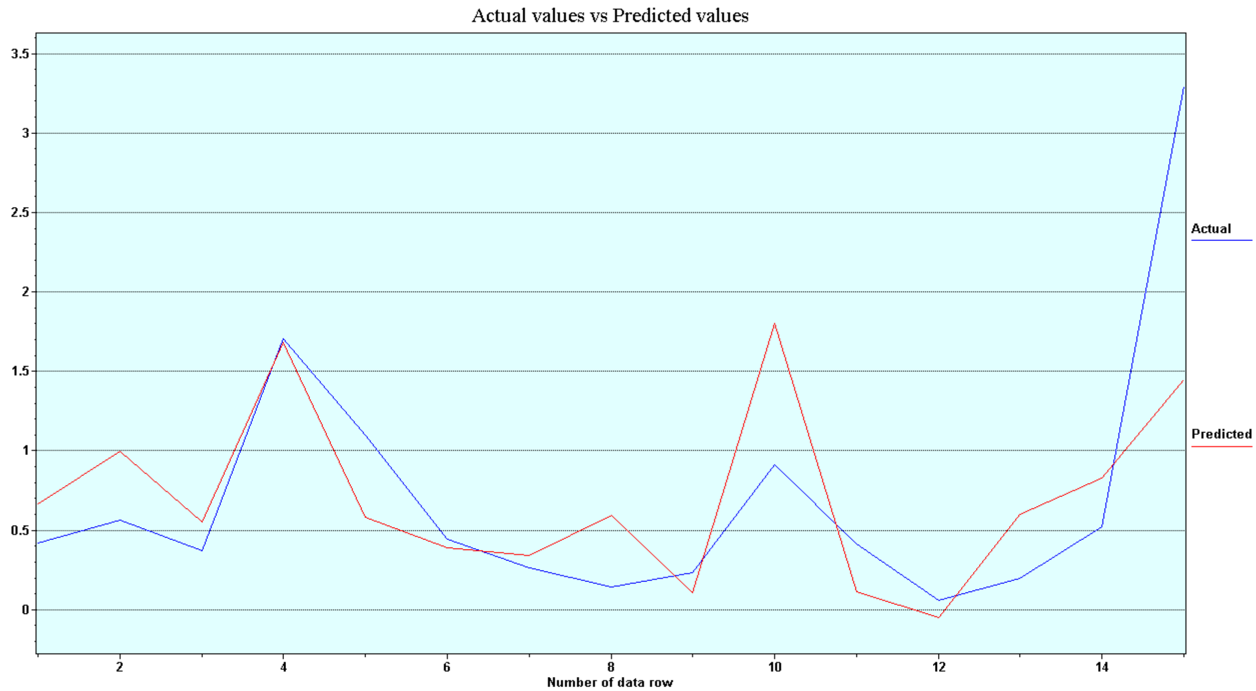
Data based on analysis of regional wind stress (correlated with transport in Shelikof Strait) for spring 2001 in the Gulf of Alaska and inferred from satellite tracked drifters indicate that advection was average and circulation was average, a sign of average recruitment. Advection was given a score of 2.0.

A nonlinear neural network model with one input neuron (larval abundance), 3 hidden neurons, and one output neuron (recruitment) was used to relate larval abundance (catch/m^2) to age recruitment abundance (billions). The model estimated 6 weighting parameters.

The data used was

Year	Average	Age 2
1982	66.44347	0.419118
1985	80.4266	0.564285
1987	324.9025	0.37081
1988	255.586	1.70397
1989	537.2943	1.09657
1990	335.0086	0.441219
1991	54.2223	0.264139
1992	563.6741	0.144109
1993	45.80764	0.235283
1994	124.9386	0.914687
1995	600.9925	0.412825
1996	472.0225	0.057794
1997	561.1063	0.196107
1998	73.07128	0.5215
1999	102.3862	3.29389
2000	535.4901	
2001	136.2054	

The neural network model, which used the first 15 observation pairs to fit the model, has an r^2 of 0.45. A plot of the observed recruitment (actual) and that predicted from larval abundance (predicted) are given below where row number corresponds to the rows of the data matrix given above.



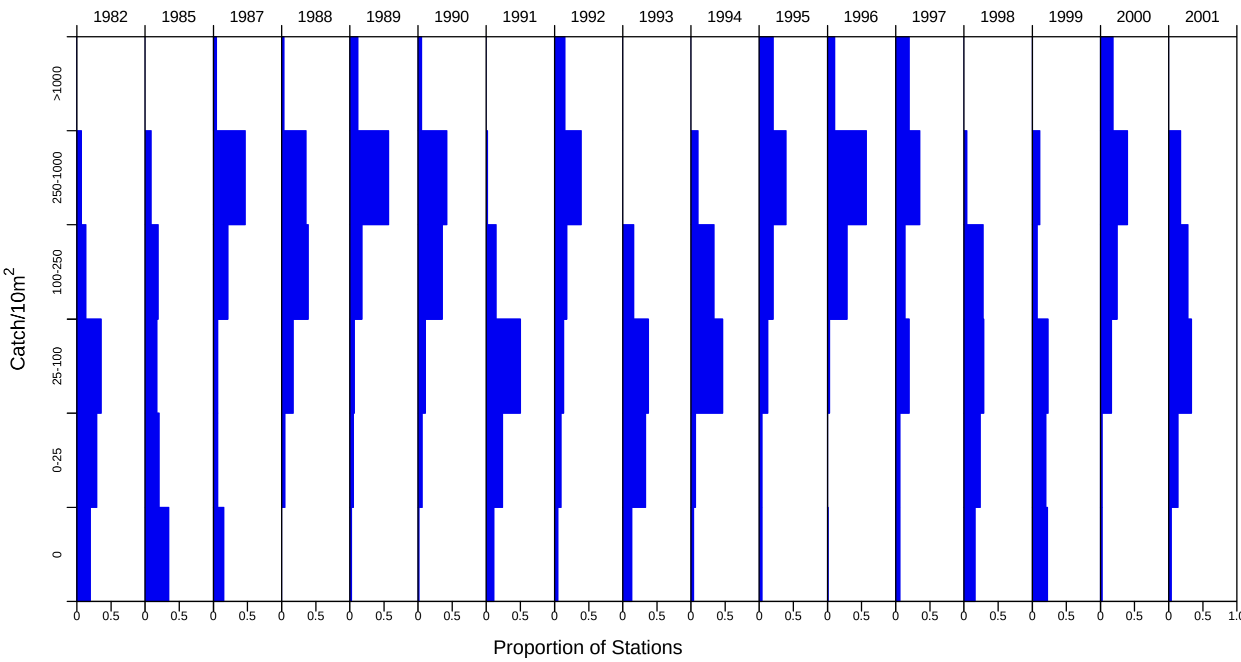
The trained network was then used to predict the recruitment for 2000 and 2001.

The predictions are

Year	*Actual Recruitment*	*Predicted Recruitment*
2000	n/a	0.572589
2001	n/a	1.935386

These values, using the 33% and 66% cutoff points given below correspond to a average 2000 year class and a strong 2001 year class.

Plotting the data by year and binning the data into catch/m^2 categories (given below) provides another view of the data. The pattern for 2001 (based on rough counts) seems similar to 1994, a year of strong recruitment.



Both of these analyses suggest that the 2001 year class may be strong. The score for larval rough counts is set to the low end of the strong range, 2.4.

The time series of recruitment from this year's assessment was analyzed in the context of a probabilistic transition. The data set consisted of estimates of age 2 abundance from 1961-2001, representing the 1959-99 year classes (see Table 1.15). There were a total of 41 recruitment data points. The 33% and 66% percentile cutoff points were calculated from the full time series (33%=0.391388 billion, 66%=0.717574 billion) and used to define the three recruitment states of weak, average and strong. The lower third of the data points were called weak, the middle third average and the upper third strong. Using these definitions, nine transition probabilities were then calculated:

1. Probability of a weak year class following a weak
2. Probability of a weak year class following an average
3. Probability of a weak year class following a strong
4. Probability of an average year class following a weak
5. Probability of an average year class following an average
6. Probability of an average year class following a strong
7. Probability of a strong year class following a weak
8. Probability of a strong year class following an average
9. Probability of a strong year class following a strong

The probabilities were calculated with a time lag of two years so that the 2001 year class could be predicted from the size of the 1999 year class. The 1999 year class was estimated to be 3.29 billion and was classified as strong. The probabilities of other recruitment states following a strong year class for a lag of 2 years (n=41) are given below:

2001 Year Class		*1999 Year Class*	*Probability*	*n*
Weak	follows	Strong	0.077	3
Average	follows	Strong	0.128	5
Strong	follows	Strong	0.128	5

The probability of an average or strong year class following a strong year class had the highest probability. The prediction element from this data source was classified as average to strong and given a score at the low end of the strong range, 2.4.

Each of the data elements was weighted equally. The larval index was used but was weighted equally with the other elements because average-to-high larval numbers are promising of good recruitment but not necessarily so.

Conclusion: Based on these five elements and the weights assigned in the table below, the FOCI forecast of the 2001 year class is average to strong.

Element	*Weights*	*Score*	*Total*
Time Sequence of R	0.23	2.40	0.552
Rain	0.2	2.45	0.49
Wind Mixing	0.2	2.25	0.45
Advection	0.16	2.00	0.32
Larval Index-abundance	0.21	2.40	0.504
Total	1.0		2.316 = **Average to Strong**

Historical trends in GOA pollock abundance based on pre-1984 bottom trawl surveys

Considerable survey work was carried out in the Gulf of Alaska prior to the start of the NMFS triennial bottom trawl surveys in 1984. Between 1961 and the mid-1980s, the most common bottom trawl used for surveying was the 400-mesh eastern trawl. This trawl (or minor variants thereof) was used by IPHC for juvenile halibut surveys in the 1960s, 1970s, and early 1980s, and by NMFS for groundfish surveys in the 1970s. The ADF&G Gulf of Alaska crab-groundfish survey, which began in the early 1990s, also uses a 400-mesh eastern trawl. Comparative work using the ADF&G 400-mesh eastern trawl and the NMFS poly-Nor'eastern trawl produced estimates of relative catchability (von Szalay and Brown in press), making it possible to evaluate trends in pollock abundance from these earlier surveys in the pollock assessment.

Von Szalay and Brown (in press) estimated a fishing power correction (FPC) for the ADFG 400-mesh eastern trawl of 3.84 (SE = 1.26), indicating that 400-mesh eastern trawl CPUE for pollock would need to be multiplied by this factor to be comparable to the NMFS poly-Nor'eastern trawl. Fishing power corrections are difficult to estimate precisely, and it should be recognized that this estimate is based on a relatively small number of paired tows (33), a limited depth range (93-156 m), did not cover the entire range of bottom types found in the Gulf of Alaska. In addition, the construction of the ADFG survey net differed in some respects to the 400-mesh eastern trawl used during the earlier surveys (D. King, pers. comm.), and towing times (~30 min.) were shorter than the surveys before 1970 (1 hr).

In most cases, earlier surveys in the Gulf of Alaska were not designed to be comprehensive, with the general strategy being to cover the Gulf of Alaska west of Cape Spencer over a period of years, or to survey a large area to obtain an index for group of groundfish, i.e., flatfish or rockfish. For example, Ronholt et al. (1978) combined surveys for several years to obtain gulfwide estimates of pollock biomass for 1973-6. There are several difficulties with such an approach, including the possibility of double-counting or missing a portion of the stock that happened to migrate between surveyed areas. Further, recruitment of abundant year classes can result in significant changes in abundance from one year to the next.

Here we explore a different approach to obtaining an annual gulfwide index of pollock abundance using generalized linear models (GLM). Although this approach is not free of assumptions, we attempt to be clear about what those assumptions are, and to fully account for uncertainty in the abundance and FPC estimates in the assessment.

Methods

Based on examination of historical survey trawl locations, we identified four index sites (one per INPFC area) that were surveyed relatively consistently during the period 1961-1983, and during the triennial survey time series (1984-99) (Fig 1.13). The index sites were designed to include a range of bottom depths from nearshore to the continental slope.

We fit a generalized linear model (GLM) to pollock CPUE data with year, site, depth strata (0-100 m, 100-200 m, 200-300 m, >300 m), and a site-depth interaction as factors. Both the pre-1984 400-mesh eastern trawl data and post-1984 triennial trawl survey data were used. For the earlier period, analysis was limited to sites where at least 20 trawls were made during the summer (May 1-Sept 15) (Table 1.10).

Pollock CPUE data consist of observations with zero catch and positive values otherwise, so we used a GLM model with Poisson error and a logarithmic link (Hastie and Tibshirani 1990). This form of GLM has been used in other marine ecology applications to analyze trawl survey data (Smith 1990, Swartzman et al. 1992). Poisson regression is a pragmatic choice for “count-like” data where the variance is proportional to the mean (McCullagh and Nelder 1983),

$$E[CPUE_i] = \mu(\boldsymbol{x_i})$$

$$Var[CPUE_i] = \varphi \ \mu(\boldsymbol{x_i}) \ ,$$

where $\mu(\boldsymbol{x_i})$ is the expected CPUE (kg km^{-2}) of the *i*th haul as a function of a vector of covariates $\boldsymbol{x_i}$, and φ is an overdispersion parameter that models the additional variability in the data relative to the Poisson distribution, where the variance is equal to the mean (Lawless 1987). Experimentation using GLM models with negative binomial error (arguably a more appropriate error model for trawl CPUE data (Power and Moser 1999)) produced similar results, although convergence problems were encountered when estimating the *k* parameter for the negative binomial. The Poisson error model was used because reliable results could be obtained using standard software packages (StatSci. 1993).

The fitted model was used to predict mean CPUE by site and depth for each year with survey data. Since we do not fit a year-site interaction term, the relative abundance by site (and depth within site) is assumed constant from one survey to the next. The estimated year effect simply scales upwards or downwards the relative abundance based on the data available in that year. This allows us to generate an overall abundance estimate when only one or two of the index sites were surveyed, but at a cost of a high residual error for the model (because relative abundance between sites can show large differences from one year to the next).

Predicted CPUEs (kg km^{-2}) were multiplied by the area within a depth strata by INPFC area (km^2) and summed to obtain proxy biomass estimates by INPFC area. Since each INPFC area contained only a single non-randomly selected index site, these proxy biomass estimates are potentially biased and would not incorporate the variability in relationship between the mean CPUE at an index site and the mean CPUE for the entire INPFC area. We used a comparison between these proxy biomass estimates by INPFC area and the actual NMFS triennial survey estimates by INPFC area for 1984-99 to obtain correction factors and variance estimates. The correction factors had the form of a ratio estimate (Cochran 1977), in which the sum of the NMFS survey biomass estimates for an INPFC area for 1984-99 is divided by the sum of the proxy biomass estimates for the same period.

Variances for biomass estimates were obtained by bootstrapping data within site-depth strata and repeating the biomass estimation algorithm. A parametric bootstrap assuming a lognormal distribution was used for the INPFC area correction factors. Variance estimates do not reflect the uncertainty in the FPC estimate. In the assessment model, however, we do not apply the FPC to the biomass estimates, but instead include the information about FPC estimate (mean and variance) as a likelihood component for relative survey catchability.

GLM results and estimates of pollock biomass in 1961-82

Analysis of deviance indicated that year, site, depth, and the site-depth interaction were all highly significant in the GLM model (Table 1.11).

Comparison of relative pollock CPUE by index site and depth strata indicate that CPUE is highest at the Sanak Island and Kodiak sites, intermediate at Chirikof site, and lowest at the Outer PWS site (Fig. 1.14). Highest CPUEs typically occurred in the 100-200 and 200-300 m depth strata. Pollock CPUE at the western sites tended to be higher in the shallow depth strata than at the eastern sites, suggesting a east-west cline in the depth distribution of pollock.

Estimates of pollock biomass are very low (<300,000 t) between1961 and 1971, increase by at least a factor of ten in 1974 and 1975, and then decline to approximately 900,000 t in 1978 (Table 1.12, also Fig. 1.15). No trend in pollock abundance is noticeable since 1978, and biomass estimates during 1978-1982 are in the same range as the post-1984 triennial survey biomass estimates. Reconciling an age-structured population model with the pollock “big bang” that these estimates suggest occurred between 1971 and 1974 will be a challenge. The coefficients of variation (CV) for GLM-based biomass estimates range between 0.24 and 0.64, and, as should be anticipated, are larger than the triennial survey biomass estimates, which range between 0.12 and 0.38.

Results are generally consistent with the multi-year combined survey estimates published previously (Table 1.13), and indicate a large increase in pollock biomass in the Gulf of Alaska occurred between the early 1960s (~200,000 t) and the mid 1970s (>2,000,000 t). Increases in pollock biomass between the1960s and 1970s were also noted by Alton et al. (1987). In the 1961 survey, pollock were a relatively minor component of the groundfish community with a mean CPUE of 16 kg/hr (Ronholt et al. 1978). Arrowtooth flounder was the most common groundfish with a mean CPUE of 91 kg/hr. In the 1973-76 surveys, the CPUE of arrowtooth flounder was similar to the 1961 survey (83 kg/hr), but pollock CPUE had increased 20-fold to 321 kg/hr, and was by far the dominant groundfish species in the Gulf of Alaska.

A key issue (which may never be adequately resolved) is relative abundance of pollock during1973-75 (based on a 400-mesh eastern trawl data) and the biomass estimates in Shelikof Strait in the early 1980s (using acoustic methods). If the FPC estimates obtained by von Szalay and Brown (in press) are applicable to vessels and trawling gear used during surveys conducted during during1973-75, available data would indicate that the increase in pollock abundance preceded the 1977 regime shift. These results do not support Anderson and Piatt’s (1999) hypothesis that the 1977 regime shift triggered the community reorganization in the Gulf of Alaska. They also found an increase in pollock abundance, but their information did not indicate an increase until around 1990. Their work is based solely on shrimp trawl surveys in inshore bays and gullies, suggesting that their results may simply be indicative of a more nearshore distribution of pollock rather than population-level changes in abundance.

Previous Gulf of Alaska pollock assessments have used a biomass estimate for 1975 obtained by expanding a 400-mesh eastern trawl biomass estimate for the Chirikof INPFC to the entire Gulf of Alaska as a part of the triennial time series (Hollowed et al. 1992, Dorn et al. 2000). Based on the results of the recent FPC work, this approach no longer tenable. Since including earlier survey biomass estimates in the assessment model does not affect estimates of current stock status, including them is useful only to compare current status with historical trends. However, it should be recognized that the estimated time series of pollock abundance is not consistent in its reliability, and that earlier biomass estimates are subject to additional caveats that would not necessarily be reflected in their (already large) confidence intervals.

Analytic Approach

Model description

Age-structured models for the period 1964 to 2001 (38 yrs) were used to assess Gulf of Alaska pollock. Population dynamics were modeled using standard formulations for mortality and fishery catch (e.g. Fournier and Archibald 1982, Deriso et al. 1985, Hilborn and Walters 1992). Year- and age-specific fishing mortality was modeled as a product of a year effect, representing the full-recruitment fishing mortality, and an age effect, representing the selectivity of that age group to the fishery. The age effect was modeled using a double-logistic function with time-varying parameters (Dorn and Methot 1990, Sullivan et al. 1997). The model was fit to time series of catch biomass, survey indices of abundance, and estimates of age and length composition from the fishery and surveys. Details of the population dynamics and estimation equations are presented in an appendix.

Model parameters were estimated by maximizing the log likelihood of the data, viewed as a function of the parameters. Log-normal likelihoods were used for survey biomass and total catch estimates, and multinomial likelihoods were used for age and length composition data.

Model likelihood components and variance assumptions are shown below:

Likelihood component	Statistical model for error	Variance assumption
Fishery total catch (1964-2001)	Log-normal	CV = 0.05
POP fishery length comp. (1964-71)	Multinomial	Sample size = 60
Fishery age comp. (1972-2000)	Multinomial	Year-specific sample size = 60-400
Shelikof EIT survey biomass (1981-2001)	Log-normal	Survey-specific CV = 0.10-0.35
Shelikof EIT survey age comp. (1981-2001)	Multinomial	Sample size = 60
NMFS bottom trawl survey biomass (1984-2001)	Log-normal	Survey-specific CV = 0.11 -0.38
NMFS bottom trawl survey age comp. (1984-99)	Multinomial	Survey-specific sample size = 38-74
NMFS bottom trawl survey length comp. (2001)	Multinomial	Sample size = 10
Egg production biomass (1981-92)	Log-normal	Survey specific CV = 0.10-0.25
ADF&G trawl survey biomass (1989-2001)	Log-normal	CV = 0.25
ADF&G survey age comp. (2000)	Multinomial	Sample size = 10
ADF&G survey length comp. (1989-2001)	Multinomial	Sample size = 10
Fishery selectivity random walk process error	Log-normal Normal	Slope CV = 0.10 (0.001 for 1964-71) Inflection age SD = 0.40 (0.004 for 1964-71)
Recruit process error (1964-1968)	Log-normal	CV =1.0

Recruitment
In most years, year-class abundance at age 2 was estimated as a free parameter. Constraints were imposed on recruitment at the start of the modeled time period to improve parameter estimability. Instead of estimating the abundance of each age of the initial age composition independently, we parameterized the initial age composition as a mean log recruitment plus a log deviation from an equilibrium age structure based on that mean initial recruitment. A penalty was added to the log likelihood so that the log deviations would have the same variability as recruitment during the assessment period. We also used the same penalty for log deviations in recruitment for 1964-68. These relatively weak constraints were sufficient to obtain fully converged parameter estimates.

Modeling fishery data
A four parameter double logistic equation was used to model fisheries selectivity. Instead of grouping years with similar selectivity patterns as in previous assessments (Hollowed et al., 1994, 1995, 1998), we allowed the parameters of the double logistic function to vary according to a random walk process (Sullivan et al. 1999). This approach allows selectivity to vary from one year to the next, but restricts the amount of variation that can occur. The resulting selectivity patterns are similar to those obtained by grouping years, but transitions between selectivity patterns occur gradually rather than abruptly. Constraining the selectivity pattern for a group of years to be similar can be done simply by reducing the year-specific standard deviation of the process error term. Since limited data are available from the Pacific Ocean perch fishery years (1964-71), the process error standard deviation for those years was assumed to be very small, so that annual changes in selectivity are not allowed during that period.

Modeling survey data
Survey abundance was assumed to be proportional to total abundance as modified by the estimated survey selectivity pattern. Expected population numbers at age for the survey were based on the mid-date of the survey, assuming constant fishing and natural mortality throughout the year. Standard deviations in the log-normal likelihood were set equal to the sampling error CV (coefficient of variation) associated with each survey estimate of abundance (Kimura 1991).

Survey catchability coefficients can be fixed or freely estimated. As in previous assessments, the NMFS bottom trawl survey catchability was fixed at one. This assumption has been used to provide management advice on pollock since 1993, and provides a precautionary constraint on the total biomass estimated by the model. Pollock are known to form pelagic aggregations and occur in nearshore areas not intensively sampled by the NMFS bottom trawl survey. Catchability coefficients for other surveys were estimated as free parameters. Egg production estimates of spawning stock biomass were included in the model by setting the age-specific selectivity equal to the estimated percent mature at age (Hollowed et al. 1991).

The EK500 acoustic system has been used to estimate biomass since 1992. Earlier surveys (1981-91) were obtained with an older Biosonics acoustic system (Table 1.5). Biomass estimates similar to the Biosonics acoustic system can be obtained using the EK500 when a volume backscattering (S_v) threshold of -58.5 dB is used (Hollowed et al. 1992). Because of the newer system's lower noise level, abundance estimates since 1992 have been based on an S_v threshold of -69 dB. We split the Shelikof Strait EIT survey time series into two periods corresponding to the two acoustic systems, and estimated separate survey catchability coefficients for each period. For the 1992 and 1993 surveys, biomass estimates using both noise thresholds were used to provide to provide information on relative catchability.

Ageing error
Ageing error for both survey and fishery age composition data was incorporated by use of a transition matrix (with elements associated with the probability of an observed age *j* being true age *j'*). This matrix was computed using the estimated percent-agreement levels based on standard deviations. That is, we computed the level of variance that would produce the observed level of agreement at different ages (Kimura and Lyons 1991). This took into account the probability that both readings were correct, both were off by one year in the same direction, or both were off by two years in the same direction. The probability that both agree and were off by more than two years was considered negligible.

Length frequency data
The assessment model was fit to length frequency data from various sources by converting predicted age distributions (as modified by age-specific selectivity) to predicted length distributions using an age-

length transition matrix. Because seasonal differences in pollock length at age are large, several transition matrices were used. For each matrix, unbiased length distributions at age were estimated for several years using age-length keys, then averaged across years. A transition matrix was estimated using second and third trimester fishery age and length data during the years (1989-98) and was used for the ADF&G survey length frequency data.. The following length bins were used: 25 - 34, 35 - 41, 42 - 45, 46 - 50, 51 - 55, 56 - 70 (cm), so that the first three bins would capture most of the summer length distribution of the age-2, age-3 and age-4 fish, respectively. A transition matrix was estimated using 1992-98 Shelikof Strait EIT survey data and used for survey length frequency data. The following length bins were used: 17 - 27, 28 - 35, 36 - 42, 43 - 50, 51 - 55, 56 - 70 (cm). Bin definitions were different for the summer and the winter transition matrices to account for the seasonal growth of the younger fish (ages 2-4). Finally, a transition matrix estimated by Hollowed et al. (1998) was used for the length-frequency data for the early period of the fishery.

Parameter estimation

A large number of parameters are estimated when using this modeling approach. More than half of these parameters are year-specific deviations in fishery selectivity coefficients. Parameters were fit using ADModel Builder, a C++ software language extension and automatic differentiation library. ADModel Builder estimates large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. The optimizer in ADModel builder is a quasi-Newton routine (Press et al. 1992). The model is determined to have converged when the maximum parameter gradient is less than a small constant (set to 1×10^{-4}). ADModel builder includes post-convergence routines to calculate standard errors (or likelihood profiles) for any quantity of interest.

A list of model parameters is shown below:

Population process modeled	Number of parameters	Estimation details
Initial age structure	Ages 3-10 = 8	Estimated as log deviances from the log mean; constrained by random deviation process error from an equilibrium unfished age structure
Recruitment	Years 1964-2001 = 38	Estimated as log deviances from the log mean; recruitment in 1964-68 constrained by random deviation process error.
Natural mortality	Age- and year-invariant = 1	Not estimated
Fishing mortality	Years 1964-2001 = 38	Estimated as log deviances from the log mean
Mean fishery selectivity	4	Slope parameters estimated on a log scale
Annual changes in fishery selectivity	4 * (No. years -1) = 148	Estimated as deviations from mean selectivity and constrained by random walk process error
Survey catchability	No. of surveys + 1 = 6	AFSC bottom trawl survey catchability not estimated, other catchabilities estimated on a log scale. Two catchability periods were estimated for the EIT survey.
Survey selectivity	8 (EIT survey: 2, BT survey: 4, ADF&G survey: 2)	Slope parameters estimated on a log scale. The egg production survey uses a fixed selectivity pattern equal to maturity at age.
Total	101 ordinary parameters + 148 process error parameters + 2 fixed parameters = 251	

Parameters Estimated Independently

Pollock life history characteristics, including natural mortality, growth, and maturity, were estimated independently. These parameters are used in the model to estimate spawning and population biomass, and obtain predictions of fishery and survey biomass. Pollock life history parameters include:

- Natural mortality (M)
- Proportion mature at age.
- Weight at age and year by fishery and by survey

Hollowed and Megrey (1990) estimated natural mortality using a variety of methods including estimates based on: a) growth parameters (Alverson and Carney 1975, and Pauly 1980), b) GSI (Gunderson and Dygert, 1988), c) monitoring cohort abundance, and d) estimation in the stock synthesis model (Methot 1993) . These methods produced estimates of natural mortality that ranged from 0.24 to 0.30. The maximum age observed was 22 years. For the assessment modeling, natural mortality was assumed to be 0.3 for all ages.

Hollowed et al. (2000) developed a model for Gulf of Alaska pollock that accounted for predation mortality. The model suggested that natural mortality declines from 0.8 at age 2 to 0.4 at age 5, and then remains relatively stable with increasing age. In addition, stock size was higher when predation mortality was included. A theoretical analysis of a simple age-structured model by Clark (1999) evaluated the effect of an erroneous M on both estimated abundance and target harvest rates. He found that "errors in estimated abundance and target harvest rate were always in the same direction, with the result that, in the short term, extremely high exploitation rates can be recommended (unintentionally) in cases where the natural mortality rate is overestimated and historical exploitation rates in the catch-at-age data are low." He proposed that this error could be avoided by using a conservative (low) estimate of natural mortality. This suggests that the current approach of using a potentially low but still somewhat credible estimate of M for assessment modeling is consistent with the precautionary approach. However, it should be emphasized that the role of pollock as prey in the Gulf of Alaska ecosystem cannot be fully evaluated using a single species assessment model (Hollowed et al. 2000).

Maturity at age for Gulf of Alaska pollock was estimated by Hollowed et al (1991) as given below:

				Age				
2	3	4	5	6	7	8	9	10+
0.034	0.116	0.325	0.639	0.867	0.960	0.989	0.997	1.000

Year-specific weight-at-age estimates are used in the model to obtain expected catches in biomass. Where possible, year and survey-specific weight-at-age estimates are used to obtain expected survey biomass. For each data source, unbiased estimates of length at age were obtained using year-specific age-length keys. Bias-corrected parameters for the length-weight relationship, $W = a\ L^b$, were also estimated. Weights at age was estimated by multiplying length at age by the predicted weight based on the length-weight regressions.

Model selection and evaluation

Including early trawl surveys in the assessment model

Biomass estimates from 400-mesh eastern trawl surveys from 1961-82 were included in the assessment model by adding a log-normal likelihood with the standard deviation set equal to the CV of the biomass estimate. This approach is identical to how other survey observations are treated in the assessment model.

Survey catchability was estimated subject to a log likelihood component:

$$\log L = -\frac{(q_1/q_2 - F\hat{P}C)^2}{2\sigma_{FPC}^2}$$

where q_1 is the catchability of the NMFS bottom trawl survey, q_2 is the catchability of historical 400-mesh eastern trawl surveys, $F\hat{P}C$ is the estimated fishing power correction (= 3.84), and σ_{FPC} is the standard error of the FPC estimate (= 1.26). As in previous assessments, it was assumed that catchability = 1 for the NMFS bottom trawl survey. The assessment model started in 1961 (in previous assessments, the model started in 1964). Pollock length composition data from 400-mesh eastern trawl surveys were available for ten years (1961, 1962, 1972, 1973, 1974, 1975, 1978, 1980, 1981, 1982). A length transition matrix from Hollowed et al. (1998) was used to obtain expected length composition from model estimates of number at age. A two-parameter logistic function was used to model survey selectivity.

The model fit to the 1961 and 1962 biomass estimates and for the 1978-82 estimates is relatively good (Fig. 1.16). The model is unable to fit simultaneously the very low biomass estimates in 1970 and 1971 and the very high biomass estimates in 1974 and 1975, and chooses a stock biomass trajectory in the middle of these extreme values. The estimated catchability of the 400-mesh eastern trawl survey time series was 0.154, which implies an FPC of 6.48, indicating that other data used to fit the model is more consistent with a higher FPC for the historical 400-mesh eastern trawl surveys than estimated by the von Szalay and Brown (in press) comparative trawling experiment.

Comparison of biomass estimates for models with and without the 400-mesh eastern trawl surveys indicate that biomass is about 50% lower between 1964 and 1970, but relatively similar in subsequent years (Fig. 1.17). Excluding the 1975 Chirikof biomass estimate and the 1973 survey age composition from the base model results in a large increase in the estimated biomass in the early part of the modeled time period, suggesting that this information is necessary to obtain reliable population estimates prior to 1975. The addition of the 400-mesh eastern trawl survey data reduces the uncertainty in population biomass estimates prior to 1975 (Fig. 1.18). We considered the model that includes the 400-mesh eastern trawl data an improvement over the base run model, and use it this year's assessment. Although both the earlier survey data and the FPC estimate are uncertain, we have been careful to obtain reasonable estimates of that uncertainty and include them in the assessment model.

Questions concerning the comparability of pollock CPUE data from historical trawl surveys with later surveys probably can never be fully resolved. However, because of the large magnitude of the change in CPUE between the surveys in the 1960s and the early 1970s using similar trawling gear, the conclusion that there was a large increase pollock biomass seems robust. Model results suggest that population biomass in 1961, prior to large-scale commercial exploitation of the stock, may have been the lowest observed (Fig. 1.18). Early speculation about the rise of pollock in the Gulf of Alaska in the early 1970s implicated the large biomass removals of Pacific Ocean perch, a potential competitor for euphausid prey (Somerton et al. 1979, Alton et al. 1987). More recent work has focused on role of climate change (Anderson and Piatt 1999, Bailey 2000). The occurrence of large fluctuations in pollock abundance without large changes in direct fishing impacts suggests a need for conservative management. If pollock abundance is controlled primarily by the environment, or through indirect ecosystem effects, it may be difficult to reverse population declines, or to achieve rebuilding targets should the stock become depleted. Reliance on sustained pollock harvests in the Gulf of Alaska, whether by individual fishermen, processing companies, or fishing communities, may simply not be possible over the long-term.

Model Evaluation

Residual plots were prepared to examine the goodness of fit of the base-run model to the age composition data. The Pearson residuals for a multinomial distribution are

$$r_i = \frac{p_i - \hat{p}_i}{\sqrt{(\hat{p}_i(1-\hat{p}_i)/m)}} ,$$

where p_i is the observed proportion at age, $\hat{p}_i$ is the expected proportion at age, and m is the sample size (McCullagh and Nelder 1983). Figures 1.19 and 1.20 show residuals of the fit to the fishery, the Shelikof Strait EIT survey, and the NMFS trawl survey age compositions. Although there are large residuals for some ages and years, no severe pattern of residuals is evident in the fishery age composition. Two moderate patterns were apparent in the fishery data. The first is a tendency for strong year classes to gain strength from adjacent weaker year classes as they become older, producing a pattern of negative residuals for the adjacent year classes. This pattern is most apparent for the strong 1984 year class beginning in 1990 at age 6. In addition, there is a tendency for strong year classes to shift a year as they become older. This pattern is most obvious for the 1988 year class, which began to change into a 1989 year class in 1995. In the 1999 AFSC trawl survey age composition, there is a pattern of negative residuals for the younger fish, and positive residuals for the older fish, suggesting that there were more old pollock were in survey samples than is consistent with the population age structure in 1999. Estimates of large numbers of older fish in the Shumagin area in 1999 are strongly affected by a few exceptionally large tows.

In the Shelikof Strait EIT survey age composition, the most extreme residuals tend to be for juvenile fish ages two and three. Since the Shelikof Strait survey covers only a portion of winter habitat of juvenile fish, this pattern could be explained by differences in spatial distribution of different year classes. For example, the 1995 year class was uncommon in the Shelikof Strait EIT survey at age two and age three, but first appeared large numbers in the fishery age composition data as three-year-old fish in the Shumagin area in 1998. In contrast, the 1994 year class was very abundant in the Shelikof Strait EIT survey as a juveniles, but was not nearly as strong in later fishery age composition data.

The model fits to survey biomass estimates are similar to previous assessments (Dorn et al. 1999) (Fig. 1.21). Even with the Shelikof Strait EIT survey was split into two catchability periods, model is still unable to the fit high biomass estimates in early 1980's. The fit to trawl survey biomass is also relatively poor. Because of the large decrease in the NMFS trawl survey biomass estimate (65% decline) from 1999 to 2001, we examined how the model attempts to fit this pattern in more detail (Fig. 1.22). Because fishery and survey age composition data indicate a distribution of ages in the population that have been surveyed previously, the age-structured population model does not show a 65% decline over two years. Possibilities that should be mentioned, but which would be difficult to confirm or disprove, are the possibility of catastrophic adult mortality due to disease or adverse environmental conditions, or mass emigration from the Gulf of Alaska. In the previous assessment the model fit to the 1999 survey estimate was already poor, and model was instead showing a decline in expected survey biomass from 600,000 t in 1996 to around 300,000 t in 1999. The 2001 survey biomass was approximately 30% lower than the expected survey biomass in 2001. This year's updated model shows a steeper decline, but a negative residual for the 2001 survey estimate. The model results are reasonable given the high variance of the 1999 and 2001 biomass estimates (CVs of 0.38 and 0.30 respectively, compared to previous survey biomass CVs between 0.12 and 0.20). The model fit to the more uncertain observation

(1999) is poorer than biomass estimates with lower variability, and the negative residual for the 2001 survey breaks the pattern of positive residuals for the NMFS trawl survey since 1987.

A likelihood profile for NMFS trawl survey catchability shows that the likelihood is higher for models with a catchability less than one (Fig. 1.23). The best fitting models were for trawl survey catchabilities in the 0.6 to 0.7 range, although the change in log likelihood is small (less than two), indicating weak support for lower catchability estimate. This suggests that basing the pollock assessment on an assumed catchability of one for the NMFS trawl survey is reasonably consistent with available data, and likely to be somewhat conservative.

Assessment Model Results

Parameter estimates and model output are presented in a series of tables and figures. Estimated selectivity for different periods in the fishery and for surveys is given in Table 1.14 (see also Fig. 1.24). Table 1.15 gives the estimated population numbers at age for the years 1964-2000. Table 1.16 gives the estimated time series of age 3+ population biomass, age-2 recruitment, and harvest rate (catch/3+ biomass) for 1969-2000 (see also Fig. 1.25). Stock size peaked in the early 1980s at approximately twice the average unfished stock size, and is currently below average under current NPFMC harvest policies at 25-35% of unfished stock size.

Retrospective comparison of assessment results

A retrospective comparison of assessment results for the years 1993-2001 indicates the current estimated trend in spawning biomass for 1969-2001 is consistent with previous estimates (Fig. 1.26). All time series show a similar pattern of increasing spawning biomass to the early 1980's, an abrupt decline, and then a gradual decrease since 1985. Estimated spawning biomass from 1969 to 1975 is about 50% lower than the 1999 and 2000 estimates for those years because of the addition of historical trawl survey data, but is similar to earlier assessments (Hollowed et al. 1998). The estimated 2001 age composition from the current assessment shows some differences compared to the estimated age composition in the 2000 assessment (see Fig. 1.26). The estimate of age-2 abundance is much larger than the average recruitment strength assumed for this year class last year. The abundance of age-3 fish is 40% lower than last year, indicating that new survey information does not support last year’s Shelikof Strait EIT survey estimate of the 1998 year class.

Initial estimates of year-class strength are relatively uncertain, and may change as additional information becomes available. Since the initial estimate of the 1999 year class is large (3.3 billion), we compared the initial estimates of the two previous strong year classes, the 1988 and 1994 year classes, with later and presumably more accurate estimates (Fig. 1.27). The estimates of 1994 year class strength have declined substantially, and are currently about 17% of the initial estimate. In contrast, the estimate of the 1988 year class has remained relatively constant, and is currently 85% of the initial estimate. It is impossible to draw firm conclusions from this comparison other than to recognize the possibility of significant changes in initial estimates of year-class strength, and the need to be aware of this potential when making catch projections.

Stock and recruitment

Recruitment of Gulf of Alaska pollock is more variable (standard deviation of log recruitment = 1.01) than Eastern Bering Sea pollock (standard deviation of log recruitment = 0.64). Among North Pacific groundfish stocks with age-structured assessments, GOA pollock ranks second in recruitment variability after sablefish (http://www.refm.noaa.gov/stocks/specs/Data%20Tables.htm). Since 1980, Gulf of Alaska pollock has shown a pattern of strong year classes every four to six years (Fig. 1.25). Because of high recruitment variability, the mean relationship between stock size and abundance is not apparent despite good contrast in stock abundance (Fig 1.28). Strong and weak year class have been produced both at high spawning biomass and low spawning biomass. The 1972 year class (one of the largest on record) was produced by an estimated spawning biomass close to current levels, suggesting that stock still has the potential to produce strong year classes. Spawner productivity is higher at low spawning biomass compared to high spawning biomass, indicating that survival of eggs to recruitment is density-dependent (Fig. 1.28). However, this pattern of density-dependent survival emerges from strong decadal trends in spawner productivity. These decadal trends in spawner productivity have produced the pattern of increase and decline in the GOA pollock population. The last two decades have been a period of relatively low spawner productivity.

New survey information suggests that the abundance of juvenile fish (age-1 and age-2) is near record levels. We summarize information on new year classes in the table below. The overall picture is suggestive of one or possibly two strong incoming year classes of pollock in the Gulf of Alaska that will stabilize or increase population biomass and harvests over the next few years.

Year of recruitment	2001	2002	2003
Year class	1999	2000	2001
FOCI prediction	*Average*	*Average*	*Average-Strong*
Survey information	2001 Shelikof EIT survey age-2 estimate is 3.91 billion (1st in abundance out of 16 surveys)	2001 Shelikof EIT survey age-1 estimate is 274 million (7th in abundance out of 18 surveys) 2001 NMFS bottom trawl age-1 (<=20 cm) estimate is 372.6 million (1st in abundance out of 7 surveys)	

Projections and Harvest Alternatives

Reference fishing mortality rates and spawning biomass levels

Since 1997, Gulf pollock have been managed under Tier 3 of NPFMC harvest guidelines. In Tier 3, reference mortality rates are based on the spawning biomass per recruit (SPR), while biomass reference levels are estimated by multiplying the SPR by average recruitment. Estimates of the FSPR harvest rates were obtained using the life history characteristics of Gulf of Alaska pollock (Table 1.17). Spawning biomass reference levels were based on mean 1979-2000 recruitment (819 million). Spawning was assumed to occur on March 15th, and female spawning biomass was calculated using the mean weight at age for the Shelikof Strait EIT survey in 1999, 2001 and 2001 to estimate current reproductive potential. The SPR at F=0 was estimated as 0.748 kg/recruit. F_{SPR} rates depend the selectivity pattern of the fishery. Selectivity in the Gulf of Alaska pollock fishery has changed as the fishery has evolved from a foreign fishery occurring along the shelf break to a domestic fishery on spawning aggregations and in nearshore waters (Fig. 1.1). Since 1992, Gulf of Alaska pollock have been managed with time and area restrictions, and selectivity has been fairly stable. For SPR calculations, we used a selectivity pattern based on an average for 1992-2001.

Gulf of Alaska pollock F_{SPR} harvest rates are given below:

F_{SPR} rate	Fishing mortality	Equilibrium under average 1979-2000 recruitment				
		Avg. Recr. (Million)	Total 3+ biom. (1000 t)	Female spawning biom. (1000 t)	Catch (1000 t)	Harvest rate
$F_{100\%}$	0.000	818	1864	612	0	0.0%
$F_{50\%}$	0.226	818	1228	306	148	12.1%
$F_{45\%}$	0.268	818	1160	275	162	14.0%
$F_{40\%}$	0.319	818	1092	245	176	16.1%
$F_{35\%}$	0.383	818	1022	214	190	18.6%

The $B_{40\%}$ estimate of 245,000 t is similar to the estimate of 250,000 t in the 2000 assessment. Spawning biomass in 2002 is projected to be 158,300 t, which is 26% of unfished spawning biomass and below $B_{40\%}$ (245,000 t), thereby placing Gulf of Alaska pollock in sub-tier "b" of Tier 3. In sub-tier "b" the OFL and maximum permissible ABC fishing mortality rates are adjusted downwards as described by the harvest guidelines (see SAFE Summary Chapter).

2002 acceptable biological catch

The definitions of OFL and maximum permissible F_{ABC} under Amendment 56 provide a buffer between the overfishing level and the intended harvest rate, as required by NMFS national standard guidelines. Since estimates of stock biomass from assessment models are uncertain, the buffer between OFL and ABC provides a margin of safety so that assessment error will not result in the OFL being inadvertently exceeded. For Gulf of Alaska pollock, the maximum permissible F_{ABC} harvest rate is 83.5% of the OFL harvest rate. In 2001, the pollock ABC of 100,770 t recommended by the assessment author and the Plan Team was based on the maximum permissible F_{ABC}. Because new survey information suggested pollock abundance was lower than projected, it now appears that had the entire ABC been taken this year the overfishing rate would have been slightly exceeded (Fig. 1.29). Actual 2001 catches are expected to be substantially below the ABC recommendation (preliminary estimates are 73,800 t).

When an ABC based on a overestimate of stock biomass is taken, the true fishing mortality will be higher than the projected fishing mortality. Assuming that spawning biomass is proportional to mean exploitable biomass, this relationship can be approximated by

$$F_{true} \approx \hat{F} \frac{\hat{B}}{B_{true}}$$

where F_{true} is the true fishing mortality, $\hat{F}$ is the projected fishing mortality, and B_{true} and $\hat{B}$ are the true and projected spawning biomass respectively. This equation says, for example, that if the true spawning biomass is 80% of the projected spawning biomass, then the true fishing mortality rate will be

25% higher than the projected fishing mortality rate. For the maximum permissible F_{ABC}, the true spawning biomass must be within 16.5% of the estimated spawning biomass to prevent accidental overfishing,. This is true only when spawning biomass is above $B_{50\%}$. At lower spawning biomass, the buffer becomes smaller. Below $B_{40\%}$, the true spawning biomass cannot be more than about 8% lower than estimated spawning biomass to avoid overfishing (Fig. 1.30). In light of our experience in 2001 in recommending an ABC that could have resulted in overfishing, we developed an alternative that maintains a constant buffer between ABC and OFL at all stock levels. While there will always some probability of exceeding F_{OFL} due to imprecise stock assessments, it does not seem reasonable to reduce safety margin as the stock declines.

This alternative is given by the following

Define $B^* = B_{40\%} \dfrac{F_{35\%}}{F_{40\%}}$

Stock status: $B/B^* > 1$, *then* $F = F_{40\%}$

Stock status: $0.05 < B/B^* \leq 1$, *then* $F = F_{40\%} \times (B/B^* - 0.05)/(1 - 0.05)$

Stock status: $B/B^* \leq 0.05$, *then* $F = 0$

This alternative has the same functional form as the maximum permissible F_{ABC}; the only difference is that it declines linearly from B^* (= B48%) to $0.05B^*$ (Fig. 1.31).

The table below gives projections for 2002 for F_{OFL}, the maximum permissible F_{ABC}, and an adjusted $F_{40\%}$ harvest rate with a constant buffer between F_{ABC} and F_{OFL}. Projections are given for two models: a model which uses the estimated abundance of the 1999 year class (3.29 billion), and a second model where the 1999 year class is assumed to be average:

	Average 1999 year class		Estimated 1999 year class	
Harvest policy	2002 fishing mortality rate	2002 catch	2002 fishing mortality rate	2002 catch
$F_{40\%}$ adjusted (Constant buffer)	0.17	53,490	0.19	78,520
$F_{40\%}$ adjusted (Maximum permissible F_{ABC})	0.20	64,110 t	0.23	94,010 t
$F_{35\%}$ adjusted (F_{OFL})	0.24	75,480 t	0.27	110,770 t

ABC recommendation
Two of the three surveys in 2001 indicated sharp declines in the abundance of adult pollock in the Gulf of Alaska. Although assessment model also shows a decline, the decline is not a steep as indicated by the NMFS trawl survey and consequently the fit to the 2001 trawl survey biomass estimate is fairly poor. Because of the large variances of the biomass estimates from the NMFS trawl survey in both 1999 and 2001, a poor model fit should not be surprising. We believe the model estimates to be a reasonable representation of actual population abundance and age composition, although it must be acknowledged that the uncertainty of model projections may larger than in previous years.

We are reluctant to use the more optimistic recruitment scenario for ABC projections for several reasons. First, based on the retrospective bias in the estimate of 1994 year class discussed earlier, there is a good chance that 1999 year class will end up being smaller than the initial estimate. Second, increases in 2002 yield with this scenario are from large projected catches of age-3 fish. Model projections under this scenario assume that 47% of the catch in numbers will be age-3 fish. In practice, the fleet tends to avoid strong year classes of juvenile fish, as shown by dips in fishery selectivity for younger fish when the 1988 and 1994 year classes were age-2 and age-3 (Fig. 1.24). Since 1990, the catch of age-3 fish has never been higher than 20%.

Compared to the projected maximum permissible F_{ABC} for 2002 in last year's assessment of 80,760 t, the current projection is 64,110 t, representing a decrease of 21%. This change is primarily a result of new survey information indicating lower stock abundance. The lower catch in 2001 makes this decrease smaller than it would have been otherwise. It is apparent in retrospect that more conservative recommendation than the maximum permissible F_{ABC} would have been appropriate for 2001. The adjusted $F_{40\%}$ harvest rate developed above provides a constant buffer for assessment error regardless of stock size, and is nearly identical to the $F_{45\%}$ adjusted harvest rate that was used for the pollock ABC in 2000. At current stock size, we consider this harvest rate a reasonable approach to assessment uncertainty. Therefore, our ABC recommendation for 2002 is 53,490 t. We note even fairly conservative assumptions regarding the strength of the 1999 year class result in increases in ABC in 2003 and 2004.

In a preliminary evaluation of the probability of exceeding the OFL definition, we modified the assessment model to include 2002, and sampled from the joint marginal likelihood of spawning biomass and fishing mortality in 2002 using Markov chain Monte Carlo (Fig 1.32.). A chain of 1,000,000 samples was thinned by selecting every 200th sample. Analysis of the thinned MCMC chain suggests that a one-sided confidence region bounded by the current OFL definition would be 65% if 2002 catch equaled the maximum permissible ABC, and 81% if the 2002 catch equaled the author's ABC recommendation. Since the current OFL definition is based on model estimates of mean recruitment and fishery selectivity, it also would be affected by assessment error. This additional source of uncertainty is not taken into account in the results reported here.

Projections and Status Determination

A standard set of projections is required for stocks managed under Tier 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the 2002 numbers at age as projected by the assessment model. In each year, the fishing mortality rate is determined by the spawning biomass in that year and the respective harvest scenario. Recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments during 1979-2000 estimated by the assessment model. Spawning biomass is computed in each year based on the time of peak spawning (March 15) using the maturity and weight schedules in Table 1.17. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios are used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2002, are as follows ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, F is set equal to the F_{ABC} recommended in the assessment.
>
> *Scenario 3*: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
>
> *Scenario 4*: In all future years, F is set equal to the 1997-2001 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 5*: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

> *Scenario 6*: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished.)
>
> *Scenario 7*: In 2002 and 2003, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition.)

Results from scenarios 1-5 are presented in Table 1.18. Under all harvest policies, spawning biomass is projected to increase after 2002. The magnitude of the increase depends on the harvest policy, but depends to greater extent on the strength of incoming year classes

Scenarios 6 and 7 are used to make the MSFCMA's required status determination as follows:

Spawning biomass is projected to be 157,000 t in 2002 under for an FOFL harvest rate, which is less than $B_{35\%}$ (214,000 t), but greater than ½ of $B_{35\%}$. Under scenario 6, the projected mean spawning biomass in 2012 is 234,000 t, 109% of $B_{35\%}$. Therefore, Gulf of Alaska pollock are not currently overfished.

Under scenario 7, projected mean spawning biomass in 2004 is 211,000 t, which is less than $B_{35\%}$, but greater than ½ of $B_{35\%}$. Projected mean spawning biomass in 2014 is 235,000 t, 110% of $B_{35\%}$. Therefore, Gulf of Alaska pollock is not approaching overfished condition.

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Table 1.1--Walleye pollock catches (1000 t) in the Gulf of Alaska, 1964-2000. The TAC for 2001 applies to waters west of 140 ^{o} W long. only (Western, Central and West Yakutat areas) and includes the guideline harvest level for the state-managed fishery in Prince William Sound (1,420 t). Research catches for 1977-2001 are also reported.

Year	Foreign	Joint Venture	Domestic	Fishery total	TAC	Research catch
1964	1.126			1.126	---	
1965	2.749			2.749	---	
1966	8.932			8.932	---	
1967	6.276			6.276	---	
1968	6.164			6.164	---	
1969	17.553			17.553	---	
1970	9.343			9.343	---	
1971	9.458			9.458	---	
1972	34.081			34.081	---	
1973	36.836			36.836	---	
1974	61.880			61.880	---	
1975	59.512			59.512	---	
1976	86.527			86.527	---	
1977	117.834		0.522	118.356	150.000	0.089
1978	96.392	0.034	0.509	96.935	168.800	0.100
1979	103.187	0.566	1.995	105.748	168.800	0.052
1980	112.997	1.136	0.489	114.622	168.800	0.229
1981	130.324	16.857	0.563	147.744	196.930	0.433
1982	92.612	73.917	2.211	168.740	168.800	0.110
1983	81.358	134.131	0.119	215.608	256.600	0.213
1984	99.260	207.104	1.037	307.401	416.600	0.311
1985	31.587	237.860	15.379	284.826	305.000	0.167
1986	0.114	62.591	25.103	87.809	116.000	1.202
1987		22.823	46.928	69.751	84.000	0.227
1988		0.152	65.587	65.739	93.000	0.019
1989			78.392	78.392	72.200	0.073
1990			90.744	90.744	73.400	0.158
1991			100.488	100.488	103.400	0.016
1992			90.857	90.857	87.400	0.040
1993			108.908	108.908	114.400	0.116
1994			107.335	107.335	109.300	0.070
1995			72.618	72.618	65.360	0.044
1996			51.263	51.263	54.810	0.147
1997			90.130	90.130	79.980	0.048
1998			125.098	125.098	124.730	0.064
1999			95.590	95.590	94.580	0.035
2000			73.080	73.080	94.960	0.056
2001					90.690	0.077
Average (1977-2000)				119.491	140.327	0.168

Sources: 1964-85--Megrey (1988); 1986-90--Pacific Fishery Information Network (PacFIN), Pacific Marine Fisheries Commission. Domestic catches in 1986-90 were adjusted for discard as described in Hollowed et al. (1991). 1991-2000--NMFS Alaska Regional Office.

Table 1.2--Annual catches of walleye pollock (t) by management area in the Gulf of Alaska (1991-99). Catches (retained and discards) were compiled from blend data provided by the NMFS Alaska Regional Office.

Year	Utilization	Shumagin 610	Chirikof 620	Kodiak 630	West Yakutat 640	Prince William Sound 649 (state waters)	Southeast and East Yakutat 650 & 659	Total	Percent discard
1991	Retained	35,943	6,913	42,836	5,489	0	0	91,181	
	Discards	4,838	793	3,459	207	0	10	9,308	9.3%
	Total	40,781	7,706	46,295	5,696	0	10	100,488	
1992	Retained	16,014	14,171	47,467	160	0	0	77,812	
	Discards	3,477	3,066	6,408	73	1	20	13,045	14.4%
	Total	19,490	17,237	53,876	233	1	20	90,857	
1993	Retained	19,791	22,080	58,188	583	0	2	100,645	
	Discards	1,413	1,708	5,065	65	8	5	8,264	7.6%
	Total	21,204	23,788	63,253	648	8	7	108,908	
1994	Retained	16,238	19,917	58,511	6,362	0	0	101,028	
	Discards	1,028	2,321	2,453	499	2	3	6,306	5.9%
	Total	17,266	22,239	60,963	6,862	2	3	107,335	
1995	Retained	28,473	11,032	21,989	480	2,739	46	64,759	
	Discards	1,905	2,048	3,778	53	75	1	7,859	10.8%
	Total	30,378	13,080	25,768	533	2,813	47	72,618	
1996	Retained	23,100	10,150	11,571	510	775	0	46,107	
	Discards	1,100	2,143	1,789	103	19	3	5,156	10.1%
	Total	24,200	12,293	13,361	613	794	3	51,263	
1997	Retained	25,253	29,736	22,064	3,938	1,807	89	82,888	
	Discards	1,009	3,179	2,998	30	19	7	7,242	8.0%
	Total	26,262	32,916	25,062	3,968	1,826	96	90,130	
1998	Retained	28,815	48,530	38,753	6,316	1,655	8	124,077	
	Discards	370	361	262	25	2	0	1,022	0.8%
	Total	29,185	48,892	39,015	6,341	1,657	8	125,098	
1999	Retained	22,864	37,349	29,515	1,737	2,178	1	93,643	
	Discards	521	784	578	22	39	3	1,947	2.0%
	Total	23,385	38,133	30,093	1,759	2,216	4	95,590	
2000	Retained	21,380	11,314	35,078	1,917	1,181	0	70,870	
	Discards	694	443	854	191	22	4	2,209	3.0%
	Total	22,074	11,757	35,933	2,108	1,203	4	73,080	
Average (1991-2000)		25,423	22,804	39,362	2,876	1,052	20	91,537	

Table 1.3--Gulf of Alaska pollock catch at age (millions of fish).

	Age														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1976	0.00	1.91	24.21	108.69	39.08	16.37	3.52	2.25	1.91	0.31	0.00	0.00	0.00	0.00	0.00	198.25
1977	0.01	2.76	7.06	23.83	89.68	30.35	8.33	2.13	1.79	0.67	0.44	0.10	0.02	0.00	0.00	167.17
1978	0.08	12.11	48.32	18.26	26.39	51.86	12.83	4.18	1.36	1.04	0.32	0.04	0.01	0.00	0.00	176.80
1979	0.00	2.53	48.83	76.37	14.15	10.13	16.70	5.02	1.27	0.60	0.16	0.04	0.00	0.00	0.00	175.81
1980	0.25	19.01	26.50	58.31	36.63	11.31	8.61	8.00	3.89	1.11	0.50	0.21	0.08	0.03	0.00	174.42
1981	0.14	2.59	31.55	73.91	47.97	20.29	4.87	4.83	2.73	0.26	0.03	0.02	0.00	0.00	0.00	189.19
1982	0.01	10.67	55.55	100.77	71.73	54.25	10.46	1.33	0.93	0.55	0.03	0.02	0.02	0.00	0.00	306.31
1983	0.00	3.64	20.64	110.03	137.31	67.41	42.01	7.38	1.24	0.06	0.28	0.07	0.00	0.00	0.00	390.07
1984	0.34	2.37	33.00	38.80	120.80	170.72	62.55	19.31	5.42	0.10	0.07	0.03	0.03	0.00	0.00	453.54
1985	0.04	12.74	5.53	33.22	42.22	86.02	128.95	41.19	10.84	2.20	0.70	0.00	0.00	0.00	0.00	363.64
1986	0.66	8.63	20.34	10.12	19.13	7.32	8.70	9.78	2.13	0.80	0.00	0.00	0.00	0.00	0.00	87.59
1987	0.00	8.83	14.03	8.00	6.89	6.44	7.18	4.19	9.95	1.94	0.00	0.00	0.00	0.00	0.00	67.44
1988	0.17	3.05	20.80	26.95	11.94	5.10	3.45	1.62	0.34	3.21	0.00	0.00	0.00	0.00	0.00	76.62
1989	1.08	0.27	1.47	19.39	28.89	16.96	8.09	4.76	1.69	1.10	3.62	0.43	0.01	0.00	0.00	87.77
1990	0.00	2.77	2.40	2.99	9.49	40.39	13.06	4.90	1.08	0.41	0.01	0.56	0.01	0.07	0.06	78.20
1991	0.00	0.59	9.68	5.45	2.85	5.33	26.67	3.12	16.10	0.87	5.65	0.42	2.19	0.21	0.77	79.90
1992	0.05	3.25	5.57	50.61	14.13	4.02	8.77	19.55	1.02	1.49	0.20	0.73	0.00	0.00	0.00	109.41
1993	0.02	1.97	9.43	21.83	47.46	15.72	6.55	6.29	8.52	1.81	2.07	0.49	0.72	0.13	0.24	123.25
1994	0.06	1.26	4.49	9.63	35.92	31.32	12.20	4.84	4.60	6.15	1.44	1.02	0.29	0.09	0.08	113.37
1995	0.00	0.06	1.01	5.11	11.52	25.83	12.09	2.99	1.52	2.00	1.82	0.19	0.28	0.03	0.15	64.61
1996	0.00	1.27	1.37	1.12	3.50	5.11	12.87	10.60	3.14	1.53	0.80	1.43	0.35	0.23	0.16	43.48
1997	0.00	1.07	6.72	3.77	3.28	6.60	10.09	16.52	12.24	5.06	2.06	0.79	0.54	0.17	0.02	68.92
1998	0.31	0.27	26.44	36.44	15.06	6.65	7.50	11.36	14.96	10.76	3.75	0.75	0.38	0.21	0.11	134.95
1999	0.00	0.42	2.21	22.74	36.10	8.99	6.89	3.72	5.71	7.27	4.01	1.07	0.56	0.12	0.10	99.92
2000	0.08	0.98	2.84	3.47	14.65	24.63	6.24	5.05	2.30	1.24	3.00	1.52	0.30	0.14	0.04	66.48

Table 1.4--Number of aged and measured fish in the Gulf of Alaska domestic pollock fishery during1989-2000 used to estimate fishery age composition.

	Number aged			Number measured		
Year	Males	Females	Total	Males	Females	Total
1989	882	892	1,774	6,454	6,456	12,910
1990	453	689	1,142	17,814	24,662	42,476
1991	1,146	1,322	2,468	23,946	39,467	63,413
1992	1,726	1,755	3,481	31,608	47,226	78,834
1993	926	949	1,875	28,035	31,306	59,341
1994	136	129	265	24,321	25,861	50,182
1995	499	544	1,043	10,591	10,869	21,460
1996	381	378	759	8,581	8,682	17,263
1997	496	486	982	8,750	8,808	17,558
1998	924	989	1,913	78,955	83,160	162,115
1999	980	1,115	2,095	16,304	17,964	34,268
2000	1,108	972	2,080	13,167	11,794	24,961

Table 1.5--Walleye pollock biomass estimates (metric tons) from NMFS echo integration trawl surveys in Shelikof Strait, NMFS bottom trawl surveys of the Gulf of Alaska (west of 140 W. long.), egg production surveys in Shelikof Strait, and ADF&G crab/groundfish trawl surveys. The biomass of age-1 fish is not included in Shelikof Strait EIT survey estimates in 1995 and 2000 (106,900 and 54,400 t respectively). An adjustment of +1.05% was made to the AFSC bottom trawl biomass time series to account for unsurveyed biomass in Prince William Sound. In 2001, when the NMFS survey did not extend east of 147^{o} W long., an expansion factor of 2.7% derived from previous surveys was used for West Yakutat.

	EIT Shelikof Strait survey				
Year	Biosonics	Simrad EK500	AFSC bottom trawl west of 140^{o} W long.	Shelikof Strait egg production	ADF&G coastal trawl survey
1981	2,785,755			1,788,908	
1982					
1983	2,278,172				
1984	1,757,168		723,087		
1985	1,175,823			768,419	
1986	585,755			375,907	
1987			735,746	484,455	
1988	301,709			504,418	
1989	290,461			433,894	214,434
1990	374,731		825,535	381,475	114,451
1991	380,331			370,000	
1992	580,000	681,400		616,000	127,359
1993	295,785	408,200	754,337		132,849
1994		467,300			103,420
1995		618,300			
1996		745,400	665,699		122,477
1997		570,100			93,728
1998		489,900			81,215
1999			611,210		53,587
2000		334,900			102,871
2001		369,600	216,761		86,967

Table 1.6--Survey sampling effort and biomass coefficients of variation (CV) for pollock in the Gulf of Alaska bottom trawl survey in 1984-99 and the Shelikof Strait EIT survey (1981-2001). For the Gulf of Alaska bottom trawl survey, the number of measured pollock is approximate due to subsample expansions in the database, and the total number measured includes both sexed and unsexed fish.

		No. of tows with	Survey		Number aged			Number measured	
Year	No. of tows	pollock	biomass CV	Males	Females	Total	Males	Females	Total
Bottom trawl survey									
1984	929	536	0.14	1,119	1,394	2,513	8,979	13,286	24,064
1987	783	533	0.20	672	675	1,347	8,101	15,654	24,608
1990	708	549	0.12	503	560	1,063	13,955	18,967	35,355
1993	775	628	0.16	879	1,013	1,892	14,496	18,692	34,921
1996	807	668	0.15	509	560	1,069	14,653	15,961	34,526
1999	764	567	0.38	560	613	1,173	10,808	11,314	24,080
2001	489	302	0.30	NA	NA	NA	NA	NA	NA
Shelikof Strait EIT survey									
	No. of midwater tows	No. of bottom trawl tows							
1981	36	18	0.12	1,921	1,815	3,736	NA	NA	NA
1983	47	1	0.16	1,642	1,103	2,745	NA	NA	NA
1984	42	0	0.18	1,739	1,622	3,361	NA	NA	NA
1985	57	0	0.14	1,055	1,187	2,242	NA	NA	NA
1986	38	1	0.22	642	618	1,260	NA	NA	NA
1987	27	0	---	557	643	1,200	NA	NA	NA
1988	26	0	0.17	537	464	1,001	NA	NA	NA
1989	21	0	0.10	757	796	1,553	NA	NA	NA
1990	25	16	0.17	988	1,117	2,105	NA	NA	NA
1991	16	2	0.35	478	628	1,106	NA	NA	NA
1992	17	8	0.04	784	765	1,549	NA	NA	NA
1993	22	2	0.05	583	624	1,207	NA	NA	NA
1994	42	12	0.05	554	633	1,187	NA	NA	NA
1995	22	3	0.05	599	575	1,174	NA	NA	NA
1996	30	8	0.04	724	775	1,499	NA	NA	NA
1997	16	14	0.04	682	853	1,535	NA	NA	NA
1998	22	9	0.04	863	784	1,647	NA	NA	NA
2000	31	0	0.05	430	370	800	NA	NA	NA
2001	15	9	0.05	314	378	692	NA	NA	NA

Table 1.7--Number of survey hauls, number of hauls with walleye pollock, mean CPUE, biomass, coefficient of variation and mean weight from the 2001 Gulf of Alaska AFSC bottom trawl survey, by INPFC area and depth intervals.

INPFC area	Depth (m)	Number of Trawl hauls	Hauls with catch	CPUE (kg/km^2)	Biomass (t)	CV	Mean weight (kg)
Shumigan	1 - 100	95	56	1,842	76,054	0.77	0.510
	101 - 200	29	18	511	7,494	0.68	0.674
	201 - 300	9	8	513	1,429	0.36	0.825
	301 - 500	6	5	611	1,548	0.72	1.097
	All depths	139	87	1,327	86,525	0.68	0.529
Chirkof	1 - 100	56	31	725	18,871	0.42	0.174
	101 - 200	57	39	352	8,395	0.39	0.121
	201 - 300	22	19	508	5,863	0.23	0.182
	301 - 500	5	2	26	42	0.61	0.865
	All depths	140	91	487	33,171	0.26	0.158
Kodiak	1 - 100	93	46	838	32,267	0.35	0.426
	101 - 200	89	57	1,123	48,664	0.29	0.224
	201 - 300	21	19	686	7,888	0.50	0.734
	301 - 500	7	2	9	27	0.74	1.109
	All depths	210	124	875	88,846	0.21	0.293
Total	All Depths	489	302	---	208,542	0.30	---

Table 1.8--Estimated pollock numbers at age (million) from NMFS echo integration-trawl surveys in Shelikof Strait, and from NMFS bottom trawl surveys. For the acoustic survey in 1987, and the bottom trawl survey in 1973, the percent at age is given. Bottom trawl survey estimates are for the Western and Central Gulf of Alaska only (Statistical areas 610-630).

Gulf of Alaska bottom trawl survey															
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1973	3.2%	7.3%	38.2%	8.3%	11.2%	21.3%	2.5%	2.8%	2.8%	1.6%	0.8%	0.1%	0.0%	0.0%	0.0%	100.0%
1984	0.93	10.02	67.81	155.78	261.17	474.57	145.10	24.80	16.59	1.66	0.21	1.32	0.00	0.00	0.00	1159.96
1987	25.45	363.02	172.99	138.97	91.13	168.27	78.14	43.99	175.39	22.41	7.81	3.51	1.82	0.00	0.00	1292.88
1989	208.88	63.49	47.56	243.15	301.09	104.43	54.47	28.39	26.14	5.98	10.66	0.00	0.00	0.00	0.00	1094.23
1990	64.04	251.21	48.34	46.68	209.77	240.82	74.41	110.41	26.13	34.23	5.03	27.73	5.70	1.07	1.63	1147.19
1993	139.31	71.15	50.94	182.96	267.12	91.51	33.12	68.98	76.62	26.36	11.85	6.29	3.82	1.82	4.41	1036.25
1996	194.23	128.79	17.30	26.13	50.04	63.18	174.41	87.62	52.37	27.73	12.10	18.46	7.16	9.68	19.70	888.90
1999	109.73	19.17	20.94	66.76	118.94	56.80	59.04	47.71	56.40	81.97	65.18	9.67	8.28	2.50	0.76	723.85

Shelikof Strait EIT survey																
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1981	77.65	3,481.18	1,510.77	769.16	2,785.91	1,051.92	209.93	128.52	79.43	25.19	1.73	0.00	0.00	0.00	0.00	10,121.37
1983	1.21	901.77	380.19	1,296.79	1,170.81	698.13	598.78	131.54	14.48	11.61	3.92	1.71	0.00	0.00	0.00	5,210.93
1984	61.65	58.25	324.49	141.66	635.04	988.21	449.62	224.35	41.03	2.74	0.00	1.02	0.00	0.00	0.00	2,928.07
1985	2,091.74	544.44	122.69	314.77	180.53	347.17	439.31	166.68	42.72	5.56	1.77	1.29	0.00	0.00	0.00	4,258.67
1986	575.36	2,114.83	183.62	45.63	75.36	49.34	86.15	149.36	60.22	10.62	1.29	0.00	0.00	0.00	0.00	3,351.78
1987	7.5%	25.5%	55.8%	2.9%	1.7%	1.2%	1.6%	1.2%	2.1%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%	100.0%
1988	17.44	109.93	694.32	322.11	77.57	16.99	5.70	5.60	3.98	8.96	1.78	1.84	0.20	0.00	0.00	1,266.41
1989	399.48	89.52	90.01	222.05	248.69	39.41	11.75	3.83	1.89	0.55	10.66	1.42	0.00	0.00	0.00	1,119.25
1990	49.14	1,210.17	71.69	63.37	115.92	180.06	46.33	22.44	8.20	8.21	0.93	3.08	1.51	0.79	0.24	1,782.08
1991	21.98	173.65	549.90	48.11	64.87	69.60	116.32	23.65	29.43	2.23	4.29	0.92	4.38	0.00	0.00	1,109.32
1994	155.71	30.33	42.97	29.31	146.27	79.07	40.47	25.98	42.66	46.46	14.22	6.40	1.08	2.25	0.55	663.72
1995	10,000.00	467.55	71.97	71.72	98.51	235.25	116.74	51.36	15.96	10.30	13.98	5.57	2.04	0.42	0.00	11,161.37
1996	51.50	3,193.33	110.73	23.75	51.72	68.32	193.46	114.14	38.40	12.53	10.93	5.13	2.42	0.02	0.37	3,876.75
1997	66.42	179.05	1,230.48	77.54	17.69	42.98	50.48	95.27	51.52	13.96	2.34	2.97	0.91	0.45	0.00	1,832.04
1998	390.12	85.49	123.98	467.34	133.52	13.64	30.44	34.55	70.48	24.64	13.63	6.56	0.26	0.54	0.54	1,395.74
2000	4,275.17	621.45	180.36	13.61	58.41	114.11	14.63	10.95	8.53	6.79	12.05	5.99	1.67	0.92	0.00	5,324.66
2001	272.48	3,591.22	296.13	51.47	34.83	18.99	28.53	10.81	5.10	2.20	1.00	1.55	0.57	0.41	0.20	4,315.50

Table 1.9--Predictions of Gulf of Alaska pollock year-class strength. The FOCI prediction is the prediction of year-class strength made in the natal year of the year class, and was derived from environmental indices, larval surveys, and the time series characteristics of pollock recruitment. The McKelvey index is the estimated abundance of 9-16 cm pollock from the Shelikof Strait EIT survey.

Year class	FOCI prediction	Year of EIT survey	McKelvey index	Rank abundance of McKelvey index
1980		1981	0.078	10
1981				
1982		1983	0.001	18
1983		1984	0.062	12
1984		1985	2.092	3
1985		1986	0.579	4
1986				
1987		1988	0.017	17
1988		1989	0.399	5
1989		1990	0.049	15
1990		1991	0.022	16
1991		1992	0.153	9
1992	Strong	1993	0.054	14
1993	Average	1994	0.156	8
1994	Average	1995	10.004	1
1995	Average-Strong	1996	0.056	13
1996	Average	1997	0.066	11
1997	Average	1998	0.390	6
1998	Average			
1999	Average	2000	4.275	2
2000	Average	2001	0.274	7
2001	Average-Strong	---	---	---

Table 1.10--Number of tows between 1961 and 1999 used in the GLM model of pollock CPUE by year and index site. For the 400-mesh eastern trawl data, the sampling period was limited to May 1 - Sept. 15, and year-site combinations were limited to those with minimum of 20 tows.

			Index site		
Year	Sanak Is.	Chirkof	Kodiak	Outer PWS	Total
400-mesh eastern trawls					
1961	83	125	60		268
1962			78	51	129
1970	39				39
1971	65				65
1974	27				27
1975		41		44	85
1978	30	20	22	37	109
1980	32	20	37	34	123
1981	36	24	61	35	156
1982	35	20	32	35	122
Nor'eastern trawls					
1984	39	48	50	13	150
1987	22	25	19	25	91
1990	49	52	74	23	198
1993	68	91	86	27	272
1996	63	102	81	23	269
1999	47	82	69	27	225

Table 1.11--Analysis of deviance for the GLM Poisson model of pollock CPUE.

Response: Pollock CPUE (kg km^{-2})
Term added sequentially (first to last)

	Df	Deviance	Resid. Df	Resid. Dev.	F value	Pr(>F)
NULL			2327	29489.9		
Year	15	3602.7	2312	25887.2	6.4	0
Depth	3	912.0	2309	24975.2	8.1	2.33E-05
Site	3	1170.6	2306	23804.6	10.4	8.73E-07
Depth X Site	9	1003.9	2297	22800.7	3.0	0.001629

Table 1.12--Estimates of pollock biomass obtained from GLM model predictions of pollock CPUE and INPFC area expansions. Biomass estimates were multiplied by the von Szalay and Brown (in press) FPC of 3.84 for comparsion to the NMFS triennial trawl survey biomass estimates. Coefficients of variation do not reflect the variance of the FPC estimate.

Year	Biomass (t)	FPC-adjusted biomass (t)	CV
1961	50,356	193,369	0.24
1962	57,496	220,783	0.30
1970	7,979	30,640	0.42
1971	4,257	16,348	0.64
1974	1,123,447	4,314,035	0.38
1975	1,501,142	5,764,384	0.52
1978	223,277	857,383	0.31
1980	146,559	562,787	0.27
1981	257,219	987,719	0.33
1982	356,433	1,368,703	0.29

Table 1.13--Previous estimates of pollock biomass in the Gulf of Alaska from surveys using 400-mesh eastern trawls. Biomass estimates for 1973-75 are based on the same survey data.

Year	Biomass (t)	FPC-adjusted biomass (t)	Reference
1961	57,449	220,604	Ronholt et al. 1978
1961-62	91,075	349,728	Ronholt et al. 1978
1973-75	1,055,000	4,051,200	Alton et al. 1977
1973-76	739,293	2,838,885	Ronholt et al. 1978
1973-75	610,413	2,343,986	Hughes and Hirschhorn 1979

Table 1.14--Selectivity at age for Gulf pollock fisheries and surveys for base-run model. The fisheries and surveys were modeled using double logistic selectivity functions, with random walk process error for the fisheries. The fishery selectivity coefficients reported below are the average of the annual selectivity for the indicated time period, rescaled so that the maximum is one.

Age	POP fishery (1961-71)	Foreign (1972-84)	Early domestic (1985-91)	Recent domestic (1992-2001)	EIT survey	Bottom trawl survey	ADF&G bottom trawl	400-mesh eastern trawl 1961-82
2	0.001	0.039	0.040	0.033	1.000	0.160	0.051	0.120
3	0.019	0.266	0.154	0.128	1.000	0.259	0.109	0.391
4	0.425	0.763	0.417	0.386	1.000	0.413	0.218	0.752
5	1.000	1.000	0.730	0.732	0.998	0.631	0.389	0.935
6	0.947	0.925	0.943	0.925	0.992	0.872	0.596	0.986
7	0.710	0.680	1.000	0.985	0.959	1.000	0.778	0.997
8	0.365	0.336	0.849	1.000	0.813	0.898	0.900	0.999
9	0.130	0.119	0.464	0.978	0.450	0.655	0.967	1.000
10	0.038	0.036	0.154	0.427	0.133	0.425	1.000	1.000

Table 1.15--Gulf pollock numbers at age (millions of fish) estimated by the base-run model, 1961-2001.

	Age								
	2	3	4	5	6	7	8	9	10
1961	386	194	121	74	55	38	28	21	16
1962	420	286	144	90	55	41	28	21	28
1963	450	311	212	107	66	41	30	21	36
1964	103	334	230	157	79	49	30	22	42
1965	253	77	247	170	116	58	36	22	48
1966	143	188	57	182	125	85	43	27	52
1967	336	106	139	41	129	89	61	31	58
1968	417	249	78	101	29	93	64	44	66
1969	708	309	184	57	72	21	67	47	82
1970	316	524	228	129	37	47	14	47	94
1971	732	234	388	165	90	26	33	10	104
1972	1,370	542	174	282	117	64	18	24	84
1973	1,006	1,015	401	123	190	79	44	13	80
1974	3,447	745	750	285	82	128	55	32	69
1975	659	2,554	551	531	184	54	87	39	74
1976	421	488	1,869	386	368	129	38	63	83
1977	1,952	311	352	1,297	267	257	91	28	107
1978	2,646	1,444	226	243	885	184	181	66	99
1979	2,438	1,953	1,035	155	166	612	130	131	122
1980	3,470	1,802	1,412	712	106	115	432	94	186
1981	1,772	2,561	1,305	987	492	73	81	310	206
1982	419	1,310	1,862	908	675	338	51	58	379
1983	496	308	932	1,290	626	467	238	37	323
1984	193	364	218	628	856	417	321	171	266
1985	492	141	250	136	374	510	262	224	322
1986	1,650	359	97	152	74	199	279	166	398
1987	564	1,206	252	64	95	46	125	192	416
1988	155	415	870	174	42	61	30	82	444
1989	371	114	301	610	117	28	40	19	385
1990	1,702	274	84	215	414	76	17	25	294
1991	1,095	1,259	201	60	147	266	47	11	234
1992	441	810	924	145	42	97	172	30	160
1993	264	325	589	646	96	27	62	110	136
1994	144	194	236	413	431	62	17	40	169
1995	235	106	142	167	280	286	41	11	144
1996	911	173	78	101	116	191	194	28	110
1997	410	674	128	56	72	80	132	133	97
1998	57	303	492	90	38	46	51	83	149
1999	195	42	212	318	55	22	27	30	145
2000	519	143	30	141	197	33	13	16	113
2001	3,282	383	104	21	90	121	20	8	88

Table 1.16--Estimated time series of Gulf pollock biomass, recruitment, and harvest for 1969-2001 for the base-run assessment model. The harvest rate is the catch in biomass divided by the total biomass of age 3+ fish at the start of the year.

Year	2+ total biomass (1,000 t)	3+ total biomass (1,000 t)	Female spawn. biom. (1,000 t)	Age 2 recruits (million)	Catch (t)	Harvest rate	2000 Assessment results: 3+ total biomass	2000 Assessment results: Female spawn. biom.	2000 Assessment results: Age 2 recruits	2000 Assessment results: Harvest rate
1969	711	607	156	708	17,553	3%	1,087	315	850	2%
1970	772	726	157	316	9,343	1%	1,171	301	303	1%
1971	865	758	174	732	9,458	1%	1,130	304	737	1%
1972	1,073	871	197	1,370	34,081	4%	1,170	311	1,326	3%
1973	1,308	1,160	221	1,006	36,836	3%	1,384	316	843	3%
1974	1,877	1,371	264	3,447	61,880	5%	1,493	336	3,334	4%
1975	2,303	2,206	337	659	59,512	3%	2,248	387	648	3%
1976	2,401	2,339	446	421	86,527	4%	2,343	472	418	4%
1977	2,421	2,134	552	1,952	118,356	6%	2,124	559	1,951	6%
1978	2,670	2,281	593	2,646	96,935	4%	2,264	589	2,680	4%
1979	3,107	2,749	609	2,438	105,748	4%	2,739	602	2,475	4%
1980	3,702	3,192	667	3,470	114,622	4%	3,195	661	3,526	4%
1981	4,093	3,833	550	1,772	147,744	4%	3,854	547	1,784	4%
1982	4,020	3,959	612	419	168,740	4%	3,987	613	418	4%
1983	3,411	3,337	780	496	215,608	6%	3,364	786	496	6%
1984	2,726	2,697	805	193	307,401	11%	2,719	812	196	11%
1985	2,060	1,986	678	492	284,826	14%	2,004	684	500	14%
1986	1,866	1,597	612	1,650	87,809	5%	1,615	618	1,659	5%
1987	1,771	1,679	512	564	69,751	4%	1,697	518	568	4%
1988	1,622	1,597	412	155	65,739	4%	1,614	417	154	4%
1989	1,513	1,451	379	371	78,392	5%	1,465	384	367	5%
1990	1,525	1,239	408	1,702	90,744	7%	1,250	412	1,678	7%
1991	1,562	1,378	375	1,095	100,488	7%	1,381	379	1,075	7%
1992	1,810	1,738	321	441	90,857	5%	1,728	323	435	5%
1993	1,637	1,595	368	264	108,908	7%	1,582	367	265	7%
1994	1,373	1,350	425	144	107,335	8%	1,338	421	133	8%
1995	1,164	1,141	389	235	72,618	6%	1,128	385	256	6%
1996	1,037	949	352	911	51,263	5%	941	348	1,050	5%
1997	1,011	972	306	410	90,130	9%	1,000	303	533	9%
1998	898	889	236	57	125,098	14%	964	238	51	13%
1999	718	690	218	195	95,590	14%	767	239	85	12%
2000	615	540	200	519	73,080	14%	577	236	887	13%
2001	1,013	537	194	3,282	---	---				
Average										
1969-2001	1,838	1,683	409	977	99,468	6%	1,791	443	990	6%
1979-2000				818						

Table 1.17--Gulf pollock life history and fishery vectors used to estimate spawning biomass per recruit (FSPR) harvest rates. Population weight at age is the average for the bottom trawl survey in 1990-1999. Spawning weight at age is the average for the Shelikof Strait EIT survey in 1998, 2000, and 2001.

			Weight at age			
Age	Natural mortality	Fishery selectivity (Avg. 1992-2001)	Spawning (March 15)	Population (June-Aug.)	Fishery (Avg. 1998-2000)	Proportion mature females
2	0.3	0.033	0.072	0.143	0.324	0.034
3	0.3	0.128	0.215	0.356	0.507	0.116
4	0.3	0.386	0.414	0.625	0.692	0.325
5	0.3	0.732	0.581	0.799	0.851	0.639
6	0.3	0.925	0.858	0.904	0.981	0.867
7	0.3	0.985	1.073	1.022	1.167	0.960
8	0.3	1.000	1.269	1.179	1.270	0.989
9	0.3	0.978	1.318	1.286	1.391	0.997
10+	0.3	0.427	1.502	1.412	1.489	1.000

Table 1.18--Projections of Gulf pollock spawning biomass, full recruitment fishing mortality, and catch for 2002-2006 under different harvest policies. All projections begin with estimated age compositon in 2002 for the base-run model. Coefficients of variation are given in parentheses, and reflect only variability in recruitment in 2003-2006.

Harvest rate	Year	Spawning Biomass (1,000 t)		Full-recruitment fishing mortality		Catch (t)	
FOFL	2002	157.5	(0.00)	0.24	(0.00)	75,476	(0.00)
F35% adjusted	2003	166.7	(0.01)	0.25	(0.01)	99,935	(0.04)
	2004	202.7	(0.05)	0.31	(0.04)	153,837	(0.14)
	2005	235.0	(0.15)	0.35	(0.06)	197,399	(0.28)
	2006	245.7	(0.27)	0.35	(0.09)	200,286	(0.43)
max FABC	2002	158.3	(0.00)	0.20	(0.00)	64,112	(0.00)
F40% adjusted	2003	171.0	(0.01)	0.22	(0.01)	88,008	(0.03)
	2004	210.5	(0.04)	0.27	(0.04)	138,428	(0.13)
	2005	247.6	(0.14)	0.31	(0.04)	179,575	(0.25)
	2006	263.5	(0.26)	0.30	(0.06)	184,758	(0.40)
Author's F	2002	159.2	(0.00)	0.17	(0.00)	53,486	(0.00)
F40% adjusted	2003	175.1	(0.01)	0.18	(0.01)	76,077	(0.03)
	2004	218.2	(0.04)	0.23	(0.04)	122,851	(0.14)
	2005	259.7	(0.14)	0.28	(0.08)	169,536	(0.30)
	2006	278.1	(0.24)	0.28	(0.10)	181,885	(0.43)
50% of max FABC	2002	160.7	(0.00)	0.10	(0.00)	33,045	(0.00)
	2003	183.2	(0.01)	0.12	(0.01)	50,079	(0.03)
	2004	234.6	(0.04)	0.15	(0.03)	84,029	(0.11)
	2005	289.8	(0.13)	0.16	(0.00)	108,345	(0.21)
	2006	328.3	(0.24)	0.16	(0.00)	118,481	(0.33)
Average F	2002	158.0	(0.00)	0.21	(0.00)	67,991	(0.00)
(1997-2001)	2003	169.9	(0.01)	0.21	(0.00)	85,833	(0.03)
	2004	211.7	(0.05)	0.21	(0.00)	110,076	(0.09)
	2005	259.3	(0.15)	0.21	(0.00)	131,600	(0.23)
	2006	291.4	(0.26)	0.21	(0.00)	142,473	(0.36)
F = 0	2002	163.1	(0.00)	0.00	---	0	---
	2003	196.9	(0.01)	0.00	---	0	---
	2004	265.4	(0.04)	0.00	---	0	---
	2005	349.7	(0.12)	0.00	---	0	---
	2006	426.2	(0.21)	0.00	---	0	---

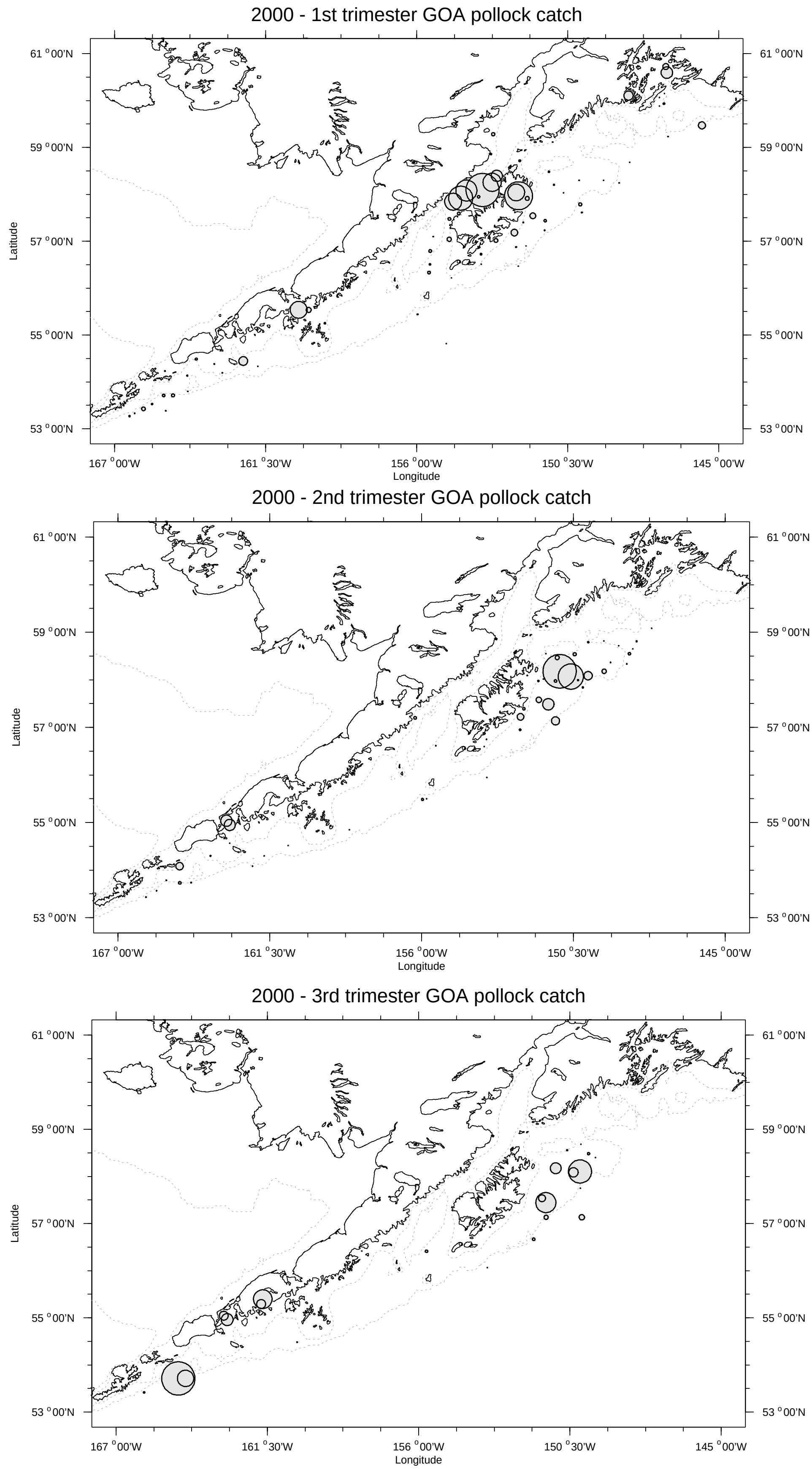
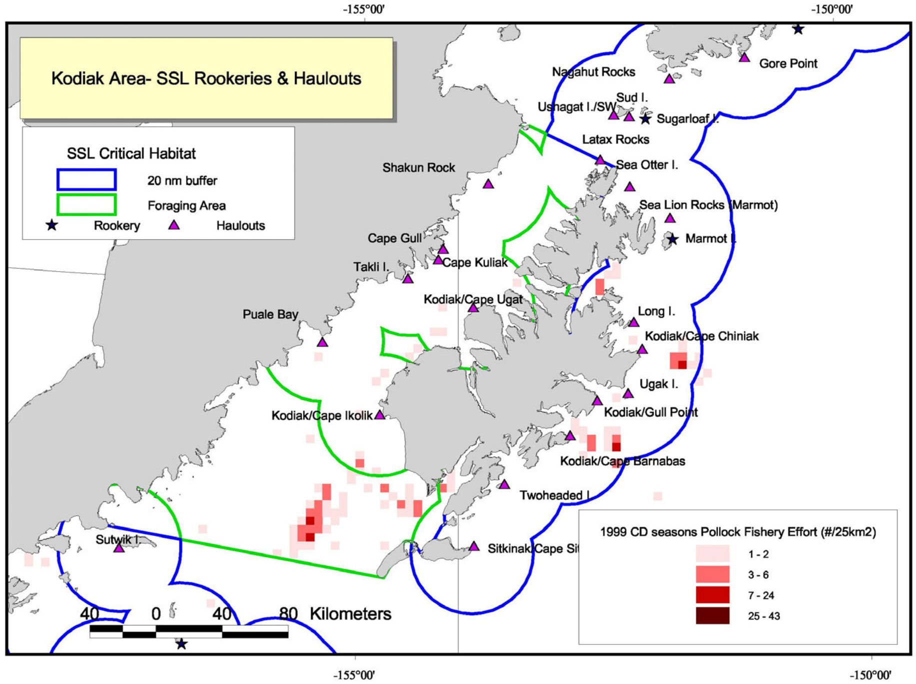


Figure 1.1--Pollock catch in 2000 by 20 sq. nmi. blocks by trimester in the Gulf of Alaska as determined by observer-recorded haul retrieval locations, representing approximately 25% of the total GOA pollock catch. The area of the circle is proportional to the catch.



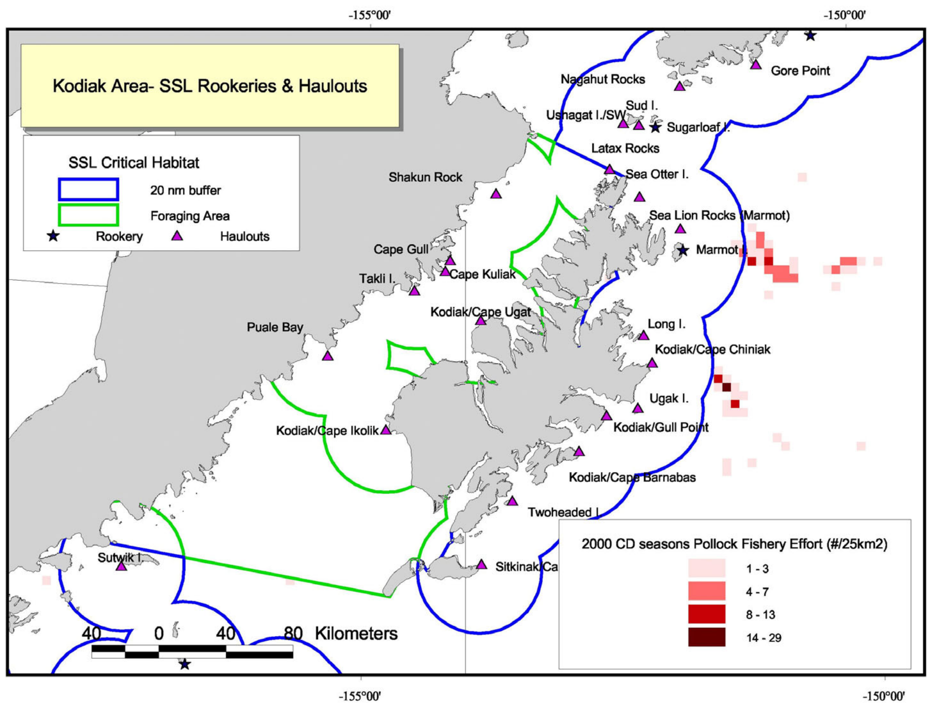


Figure 1.2--Comparison of pollock trawling effort during the C and D seasons in 1999 and 2000 in the Kodiak area showing the displacement of fishing outside critical habitat during 2000.

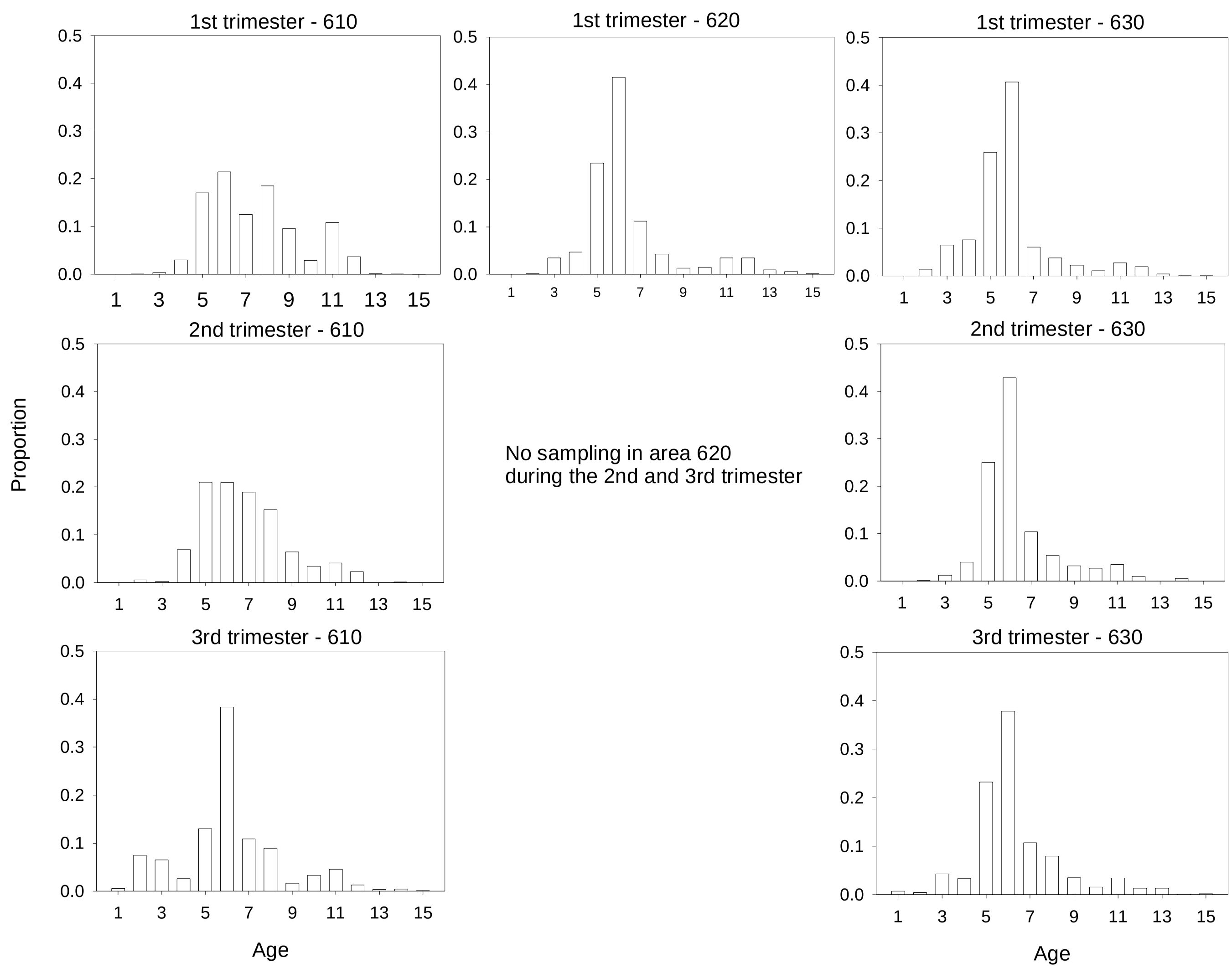


Figure 1.3–Gulf of Alaska pollock catch proportions at age by trimester and statistical area in 2000.

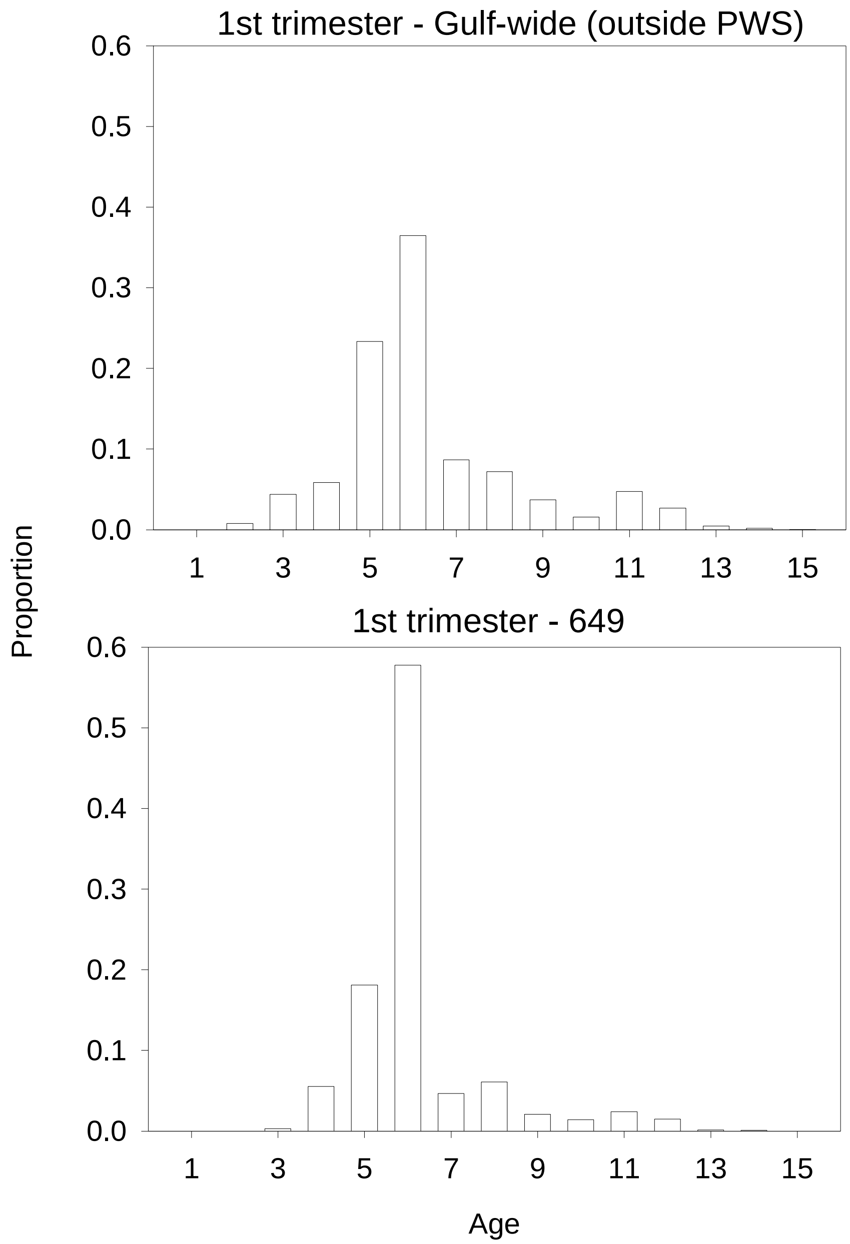


Figure 1.4–Comparison of pollock catch proportions at age inside Price William Sound with Gulf-wide estimates during the first trimester of 2000.

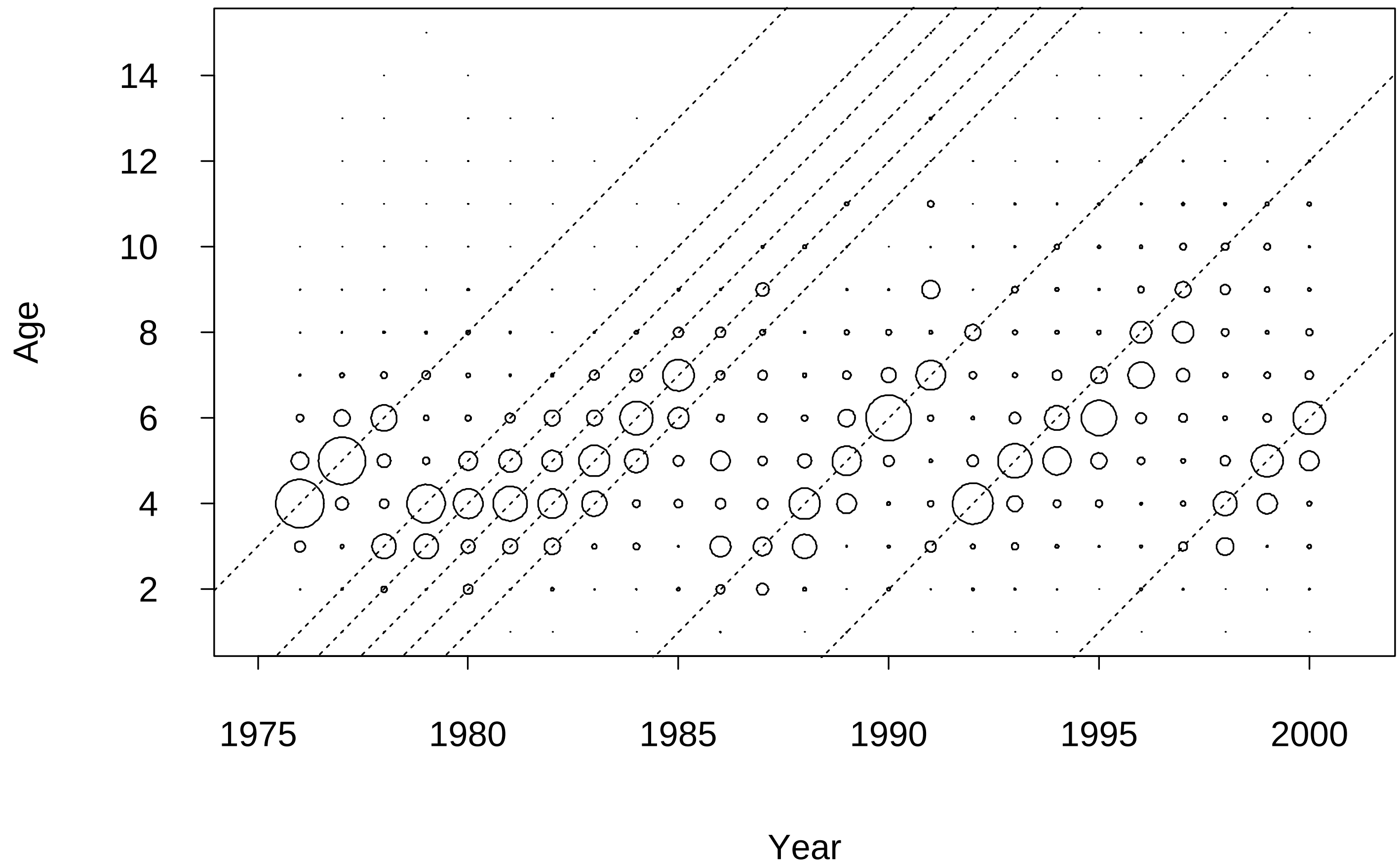


Figure 1.5–Gulf of Alaska pollock catch proportions at age (1976-2000). The diameter of the circle is proportional to the catch. Diagonal lines show the strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, and 1994).

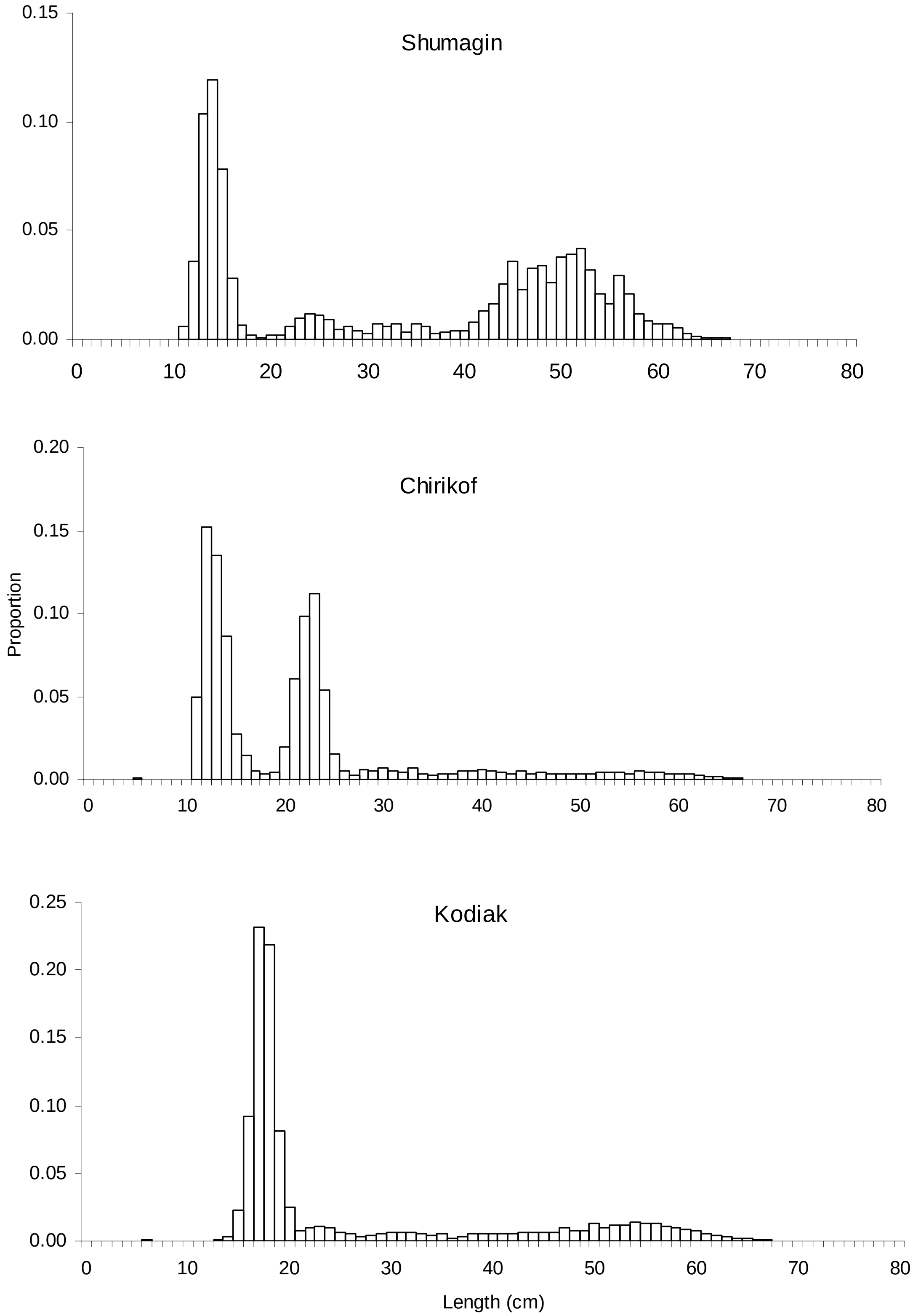


Figure 1.6–Pollock length distribution by INPFC area for the 2001 NMFS bottom trawl survey.

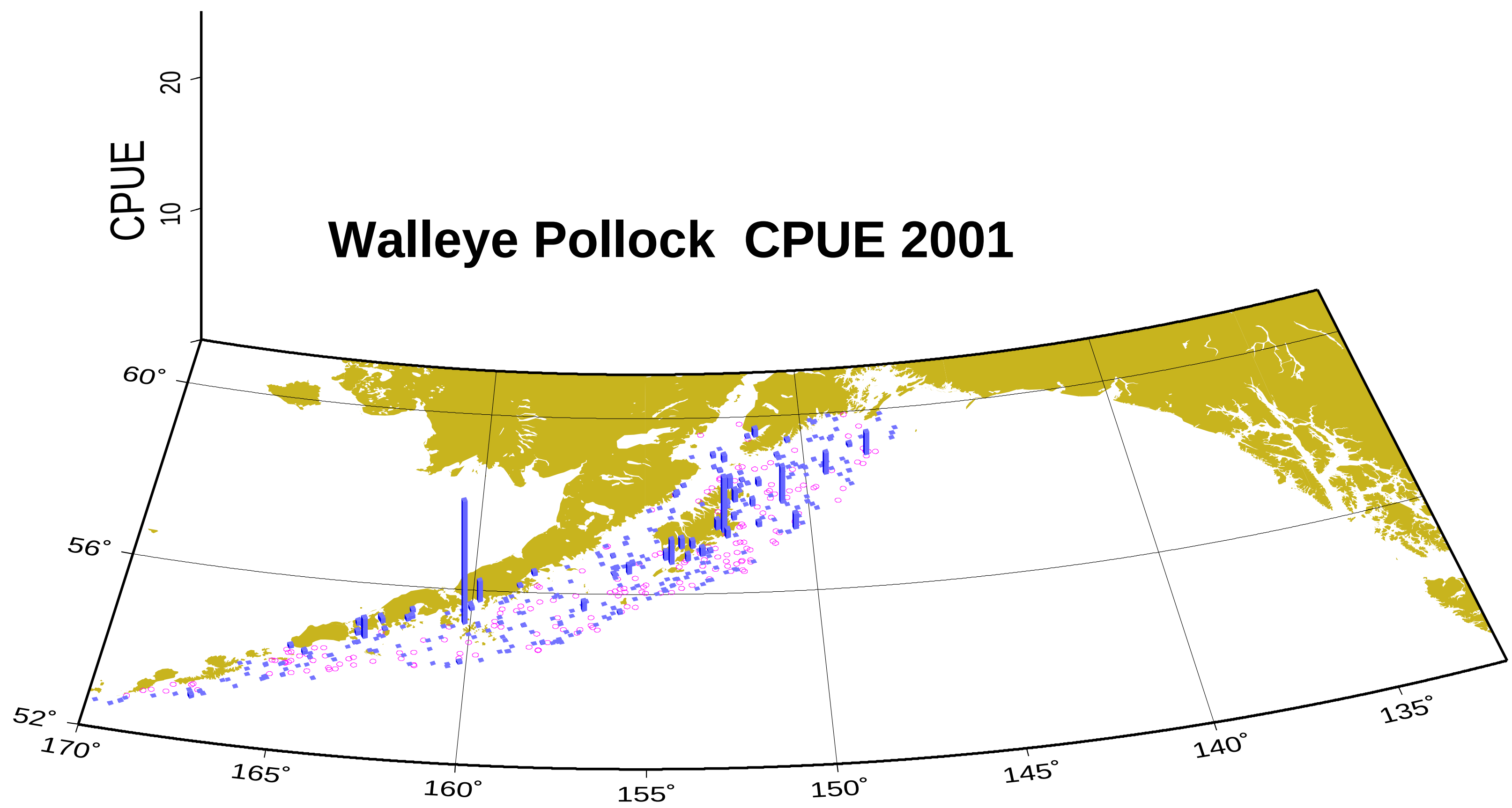
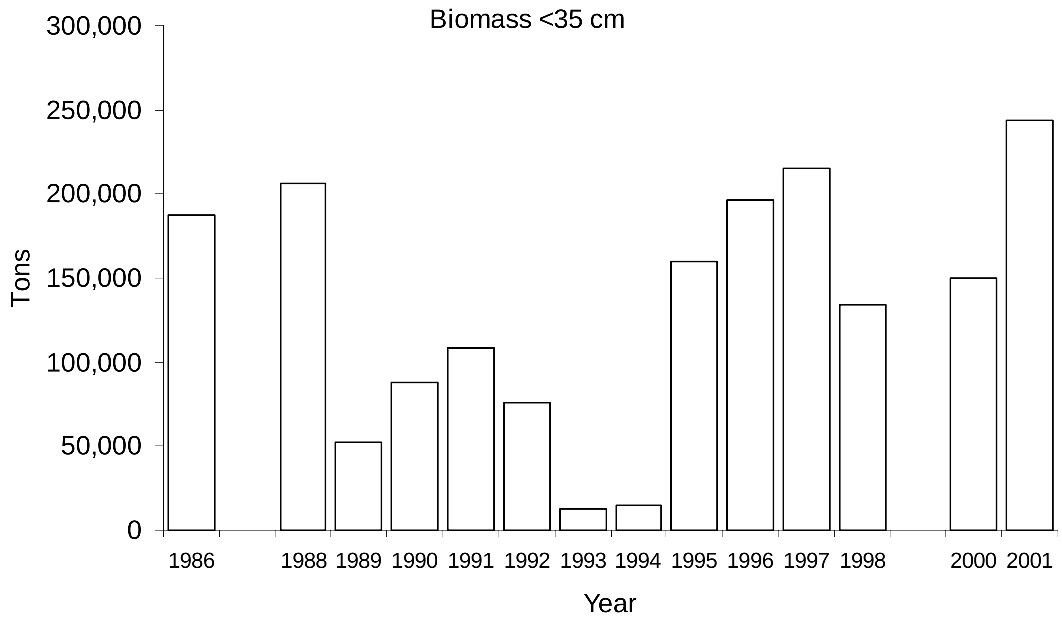


Figure 1.7–Gulf of Alaska pollock CPUE from the 2001 NMFS bottom trawl survey.



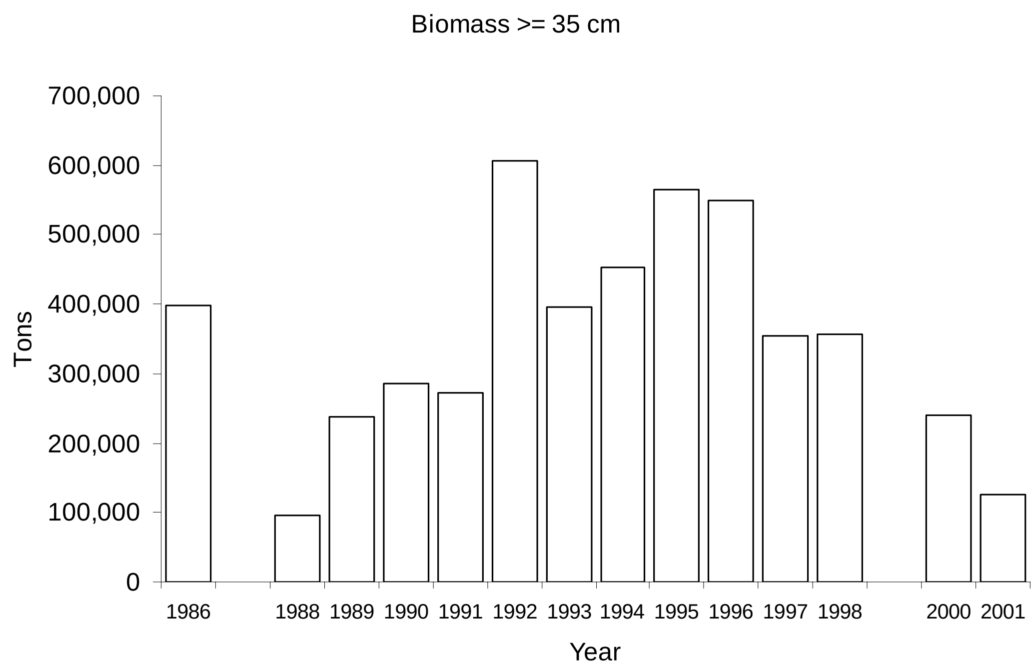


Figure 1.8–Biomass estimates of juvenile pollock (top) and adult pollock (bottom) from 1986-2001 Shelikof Strait EIT surveys.

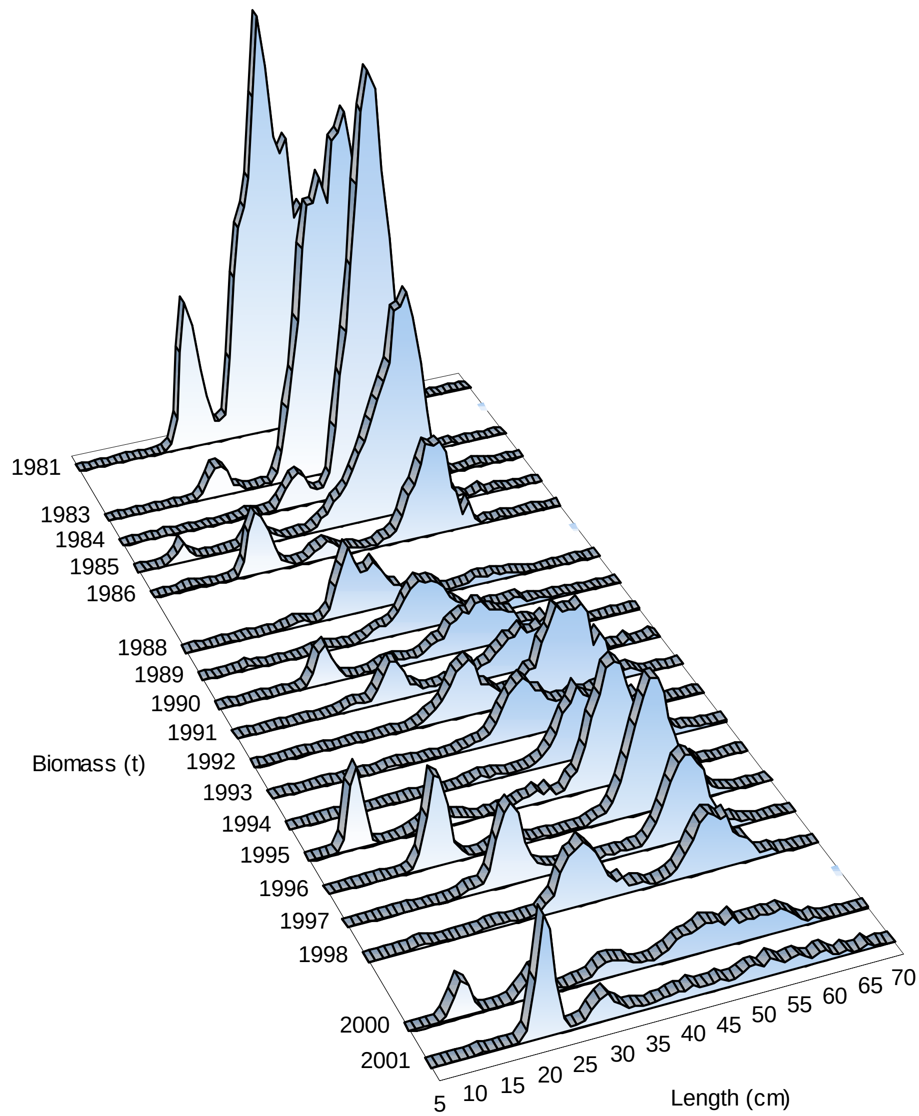


Figure 1.9–Biomass distribution by length of pollock in the Shelikof Strait EIT survey (1981-2001, except 1982,1987 and 1999).

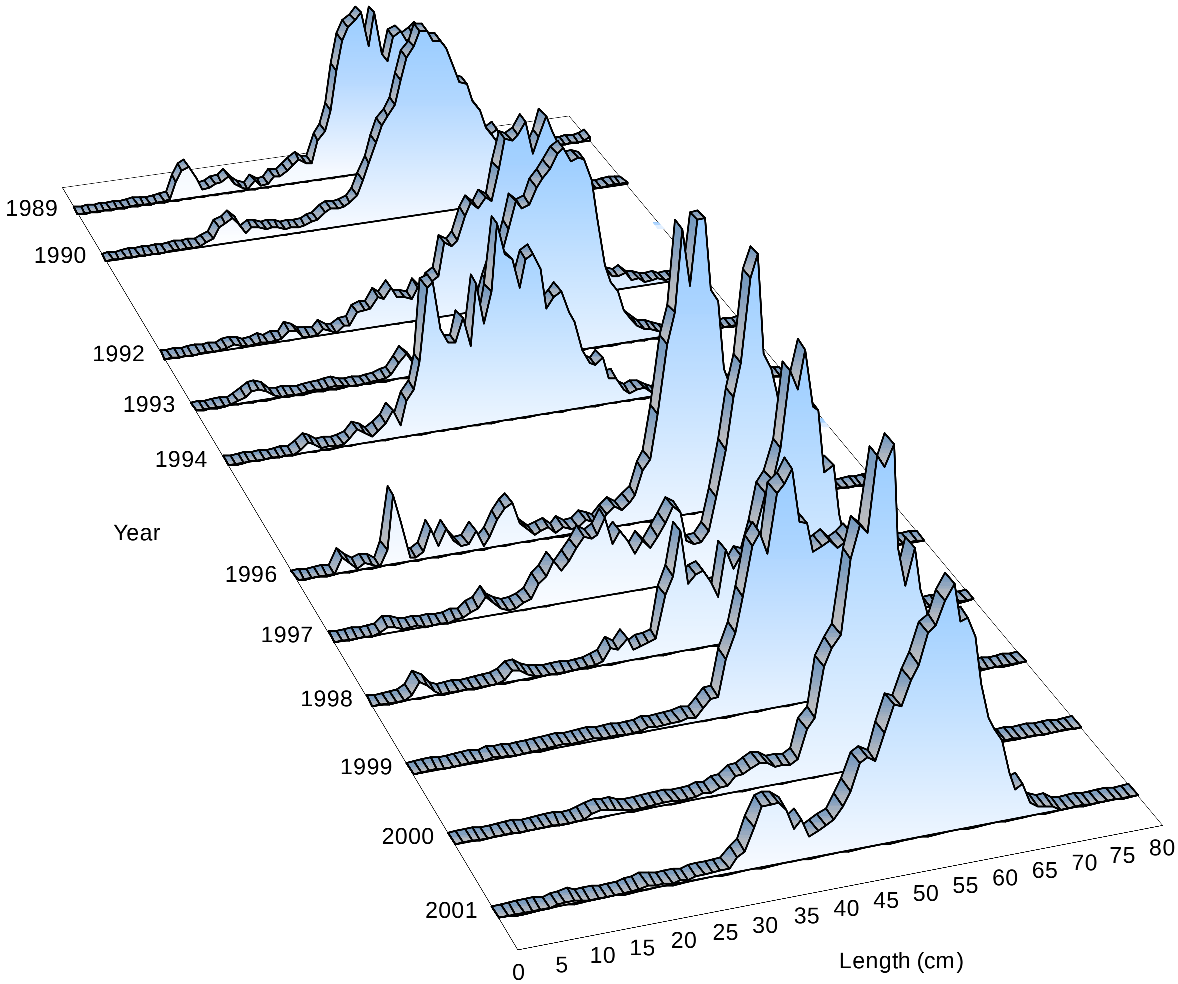


Figure 1.10–Length frequency of pollock in the ADF&G bottom trawl survey (1990-2001, except 1991 and 1995).

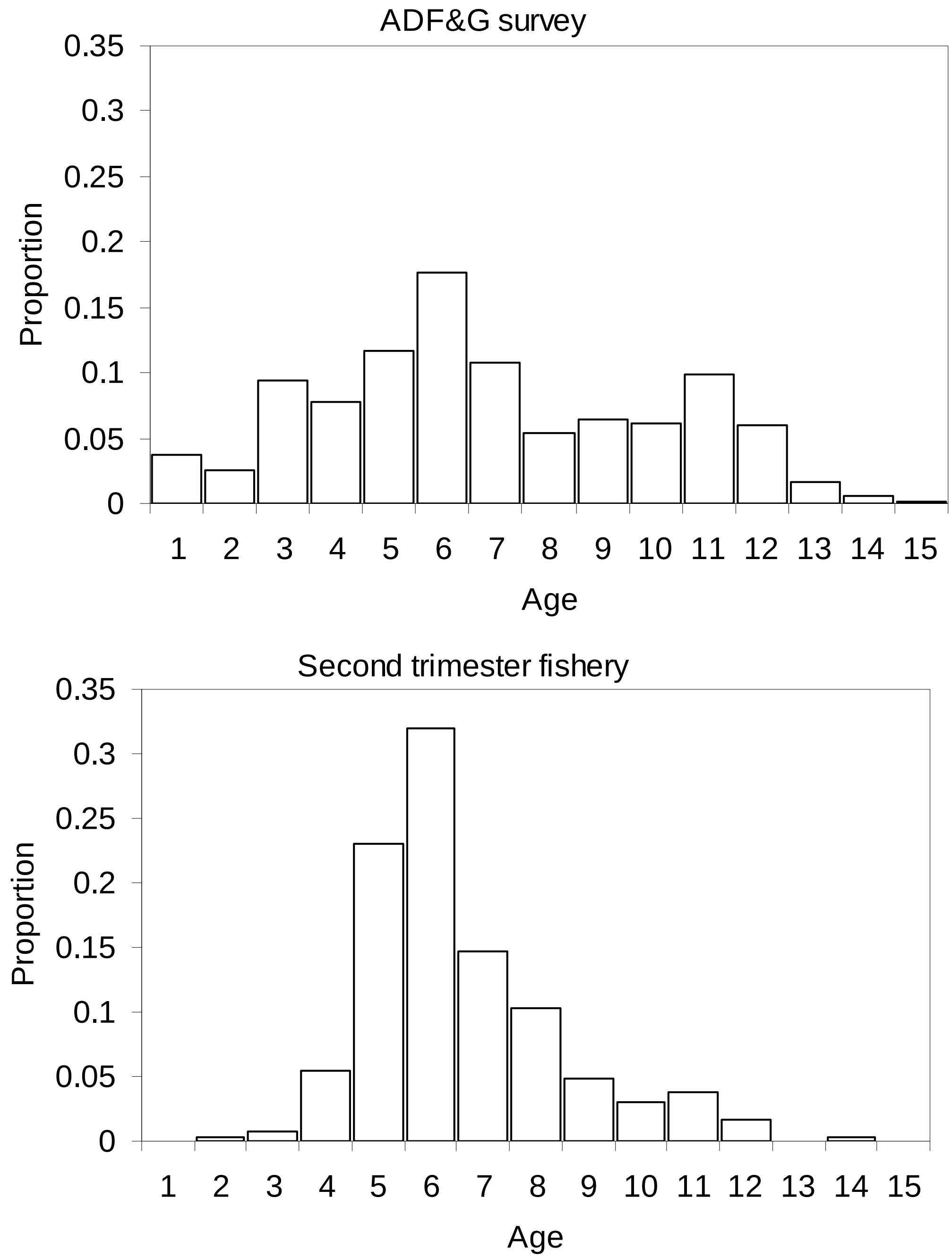


Figure 1.11–Comparison of age composition from the 2000 ADF&G crab/groundfish survey and the second trimester fishery age composition.

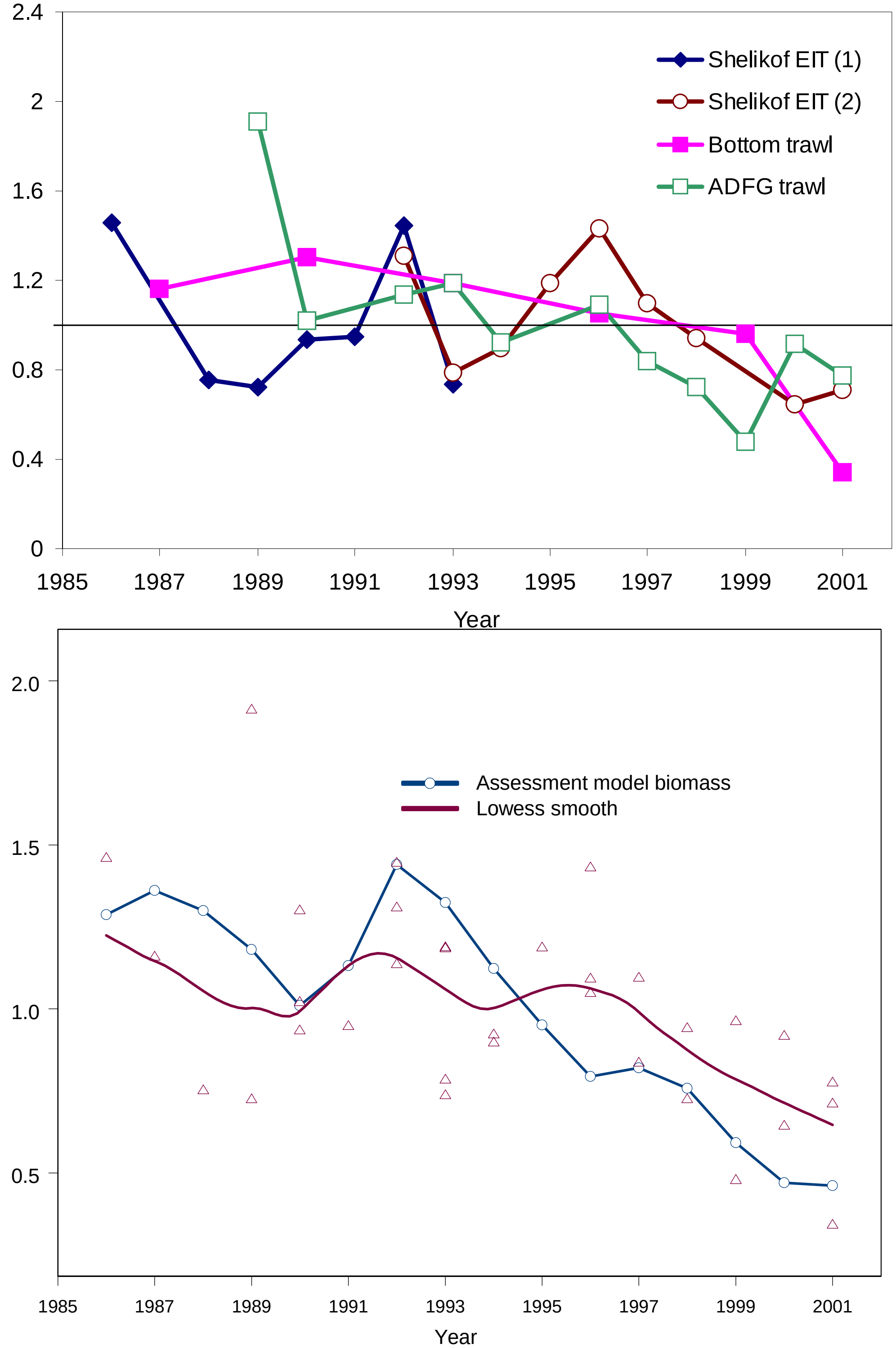


Figure 1.12–Trends in Gulf pollock biomass since 1986 for the Shelikof Strait EIT survey, the triennial bottom trawl survey, and the ADF&G coastal trawl survey. Each survey biomass estimate is divided by the average for the survey since 1986. The Shelikof Strait EIT survey is split into separate time series corresponding to the two acoustic systems used for the survey. In the bottom panel, a lowess smooth (SPLUS 1993) of the same data is compared to the estimated biomass trend from the assessment model.

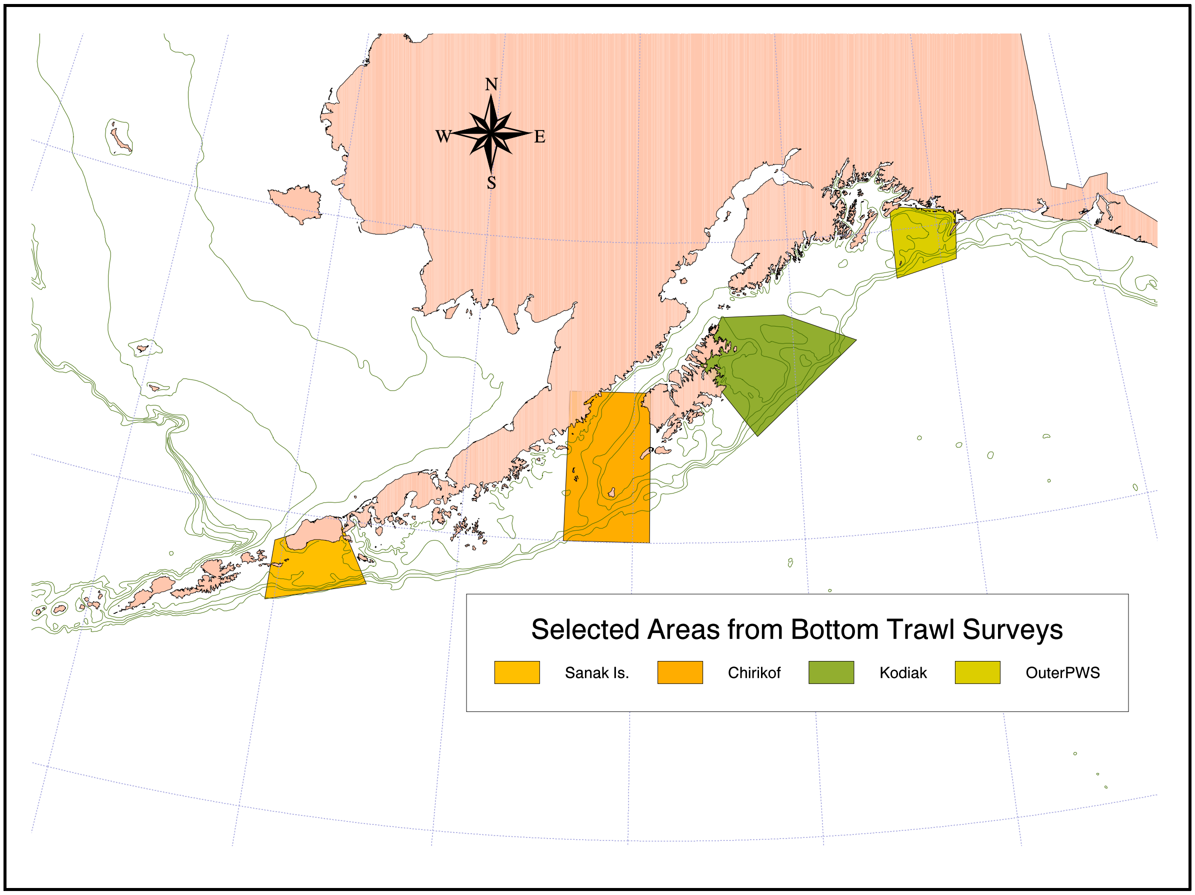


Figure 1.13–Index sites in the Gulf of Alaska used for the GLM analysis of historical pollock CPUE data.

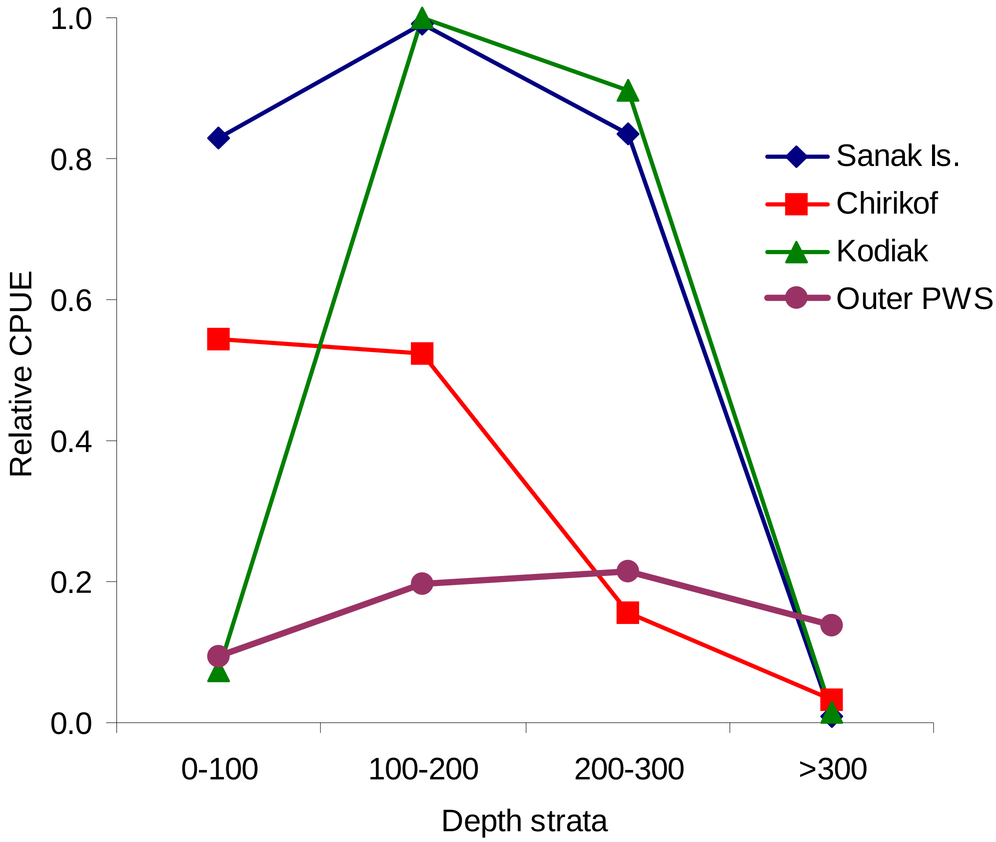


Figure 1.14–Predicted pollock CPUE by site and depth strata in the Gulf of Alaska based on a GLM model. CPUEs are scaled so that the maximum CPUE is one.

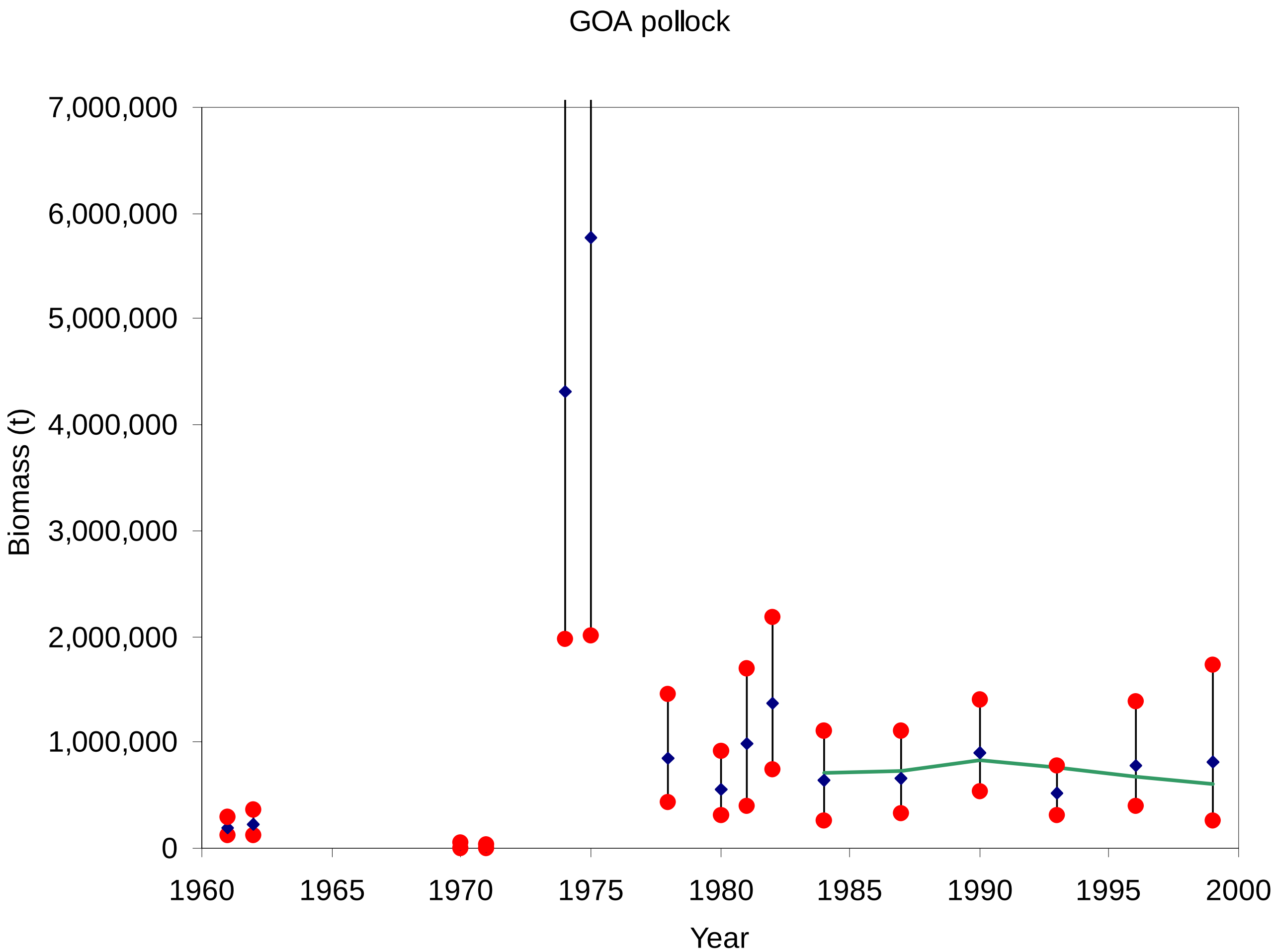


Figure 1.15–Estimated time series of pollock biomass based on a GLM model of pollock CPUE and area expansions. Ninety-five percent confidence intervals based on bootstrap resampling are also indicated. Pre-1984 estimates were multiplied by a FPC of 3.84 (von Szalay and Brown in press) to facilitate comparison with the triennial survey estimates. Confidence intervals do not reflect the variance of the FPC estimate. The solid line shows the actual design-based biomass estimates for the triennial surveys in 1984-99.

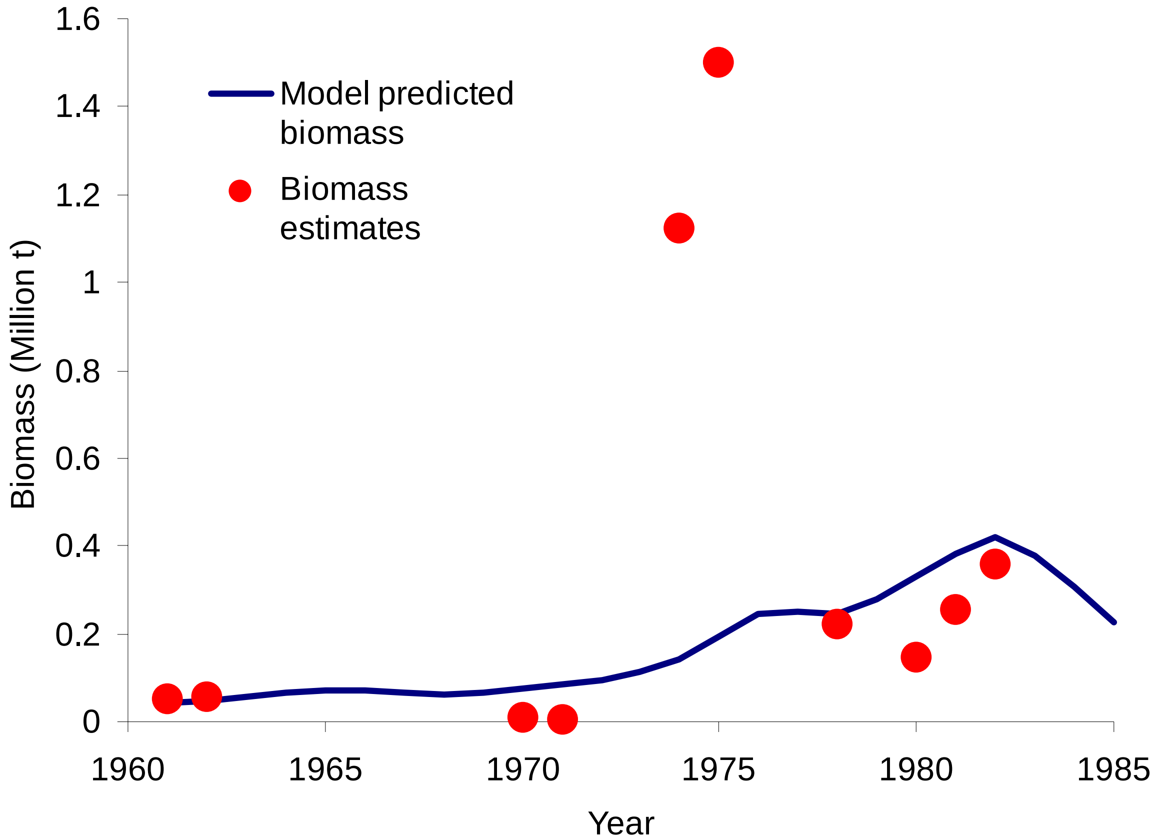


Figure 1.16–Model fit to 400-mesh eastern trawl survey biomass estimates.

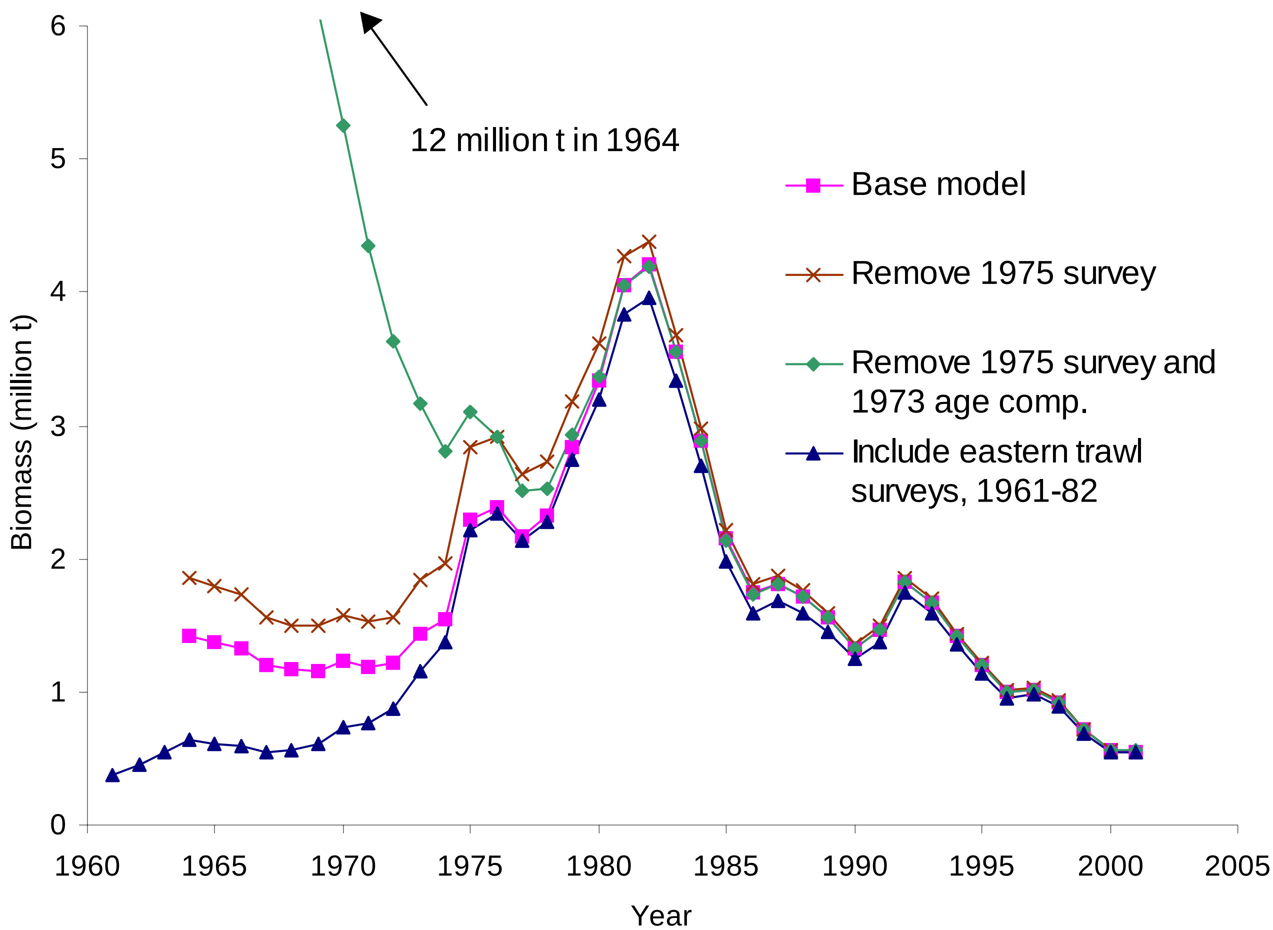


Figure 1.17–Estimates of GOA pollock age 3+ biomass for series of assessment models with different input data to evaluate the impact of including the historical 400-mesh eastern trawl survey biomass estimates. For this figure, the base model corresponds to previous assessments, which used a 1975 biomass estimate from a 400-mesh eastern trawl survey of the Chirikof INPFC area expanded to the entire Gulf of Alaska and included in the NMFS triennial time series. An age composition from a 400-mesh eastern trawl survey in 1973 was also included in NMFS triennial survey age composition.

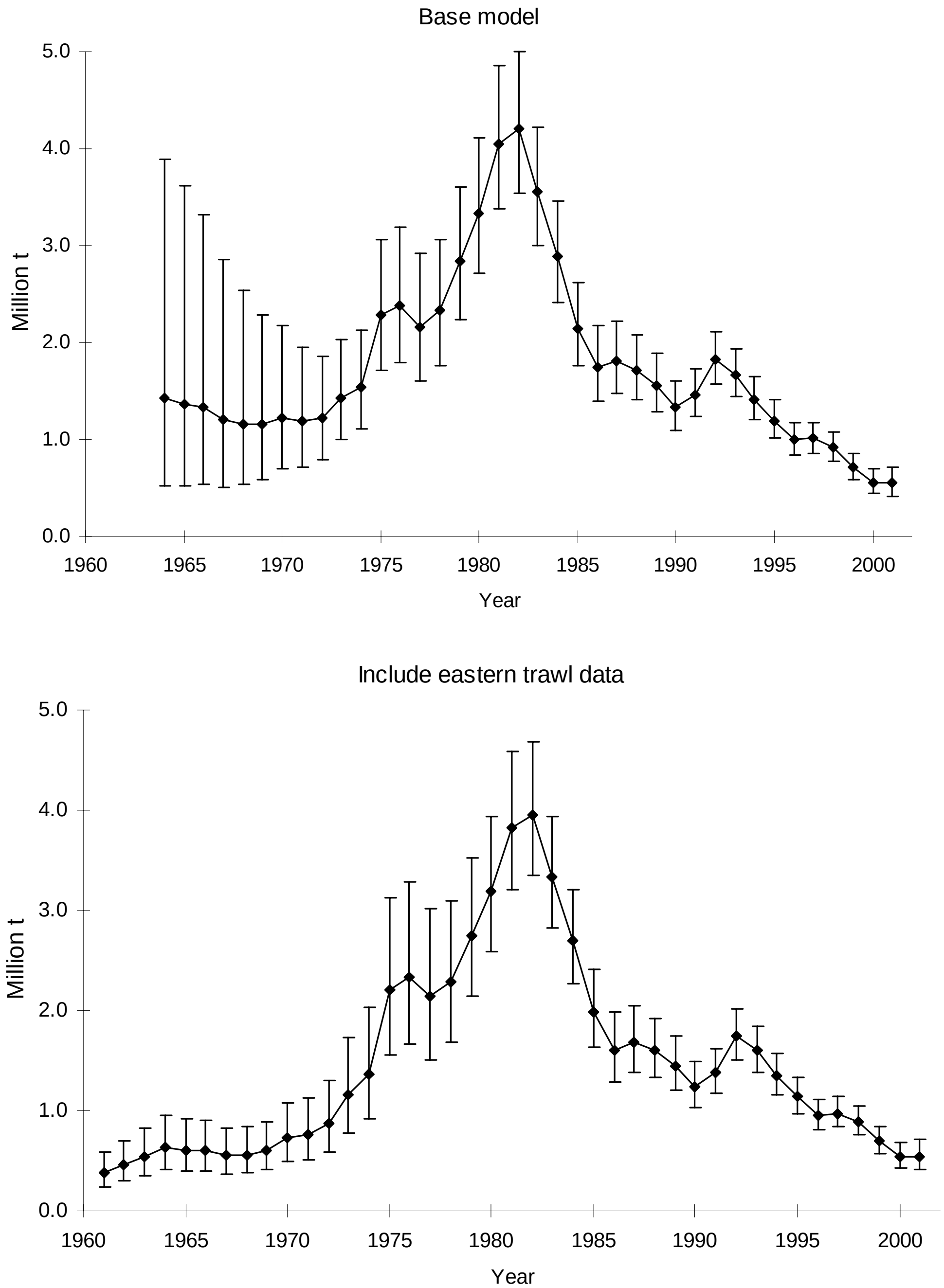


Figure 1.18–Comparison of approximate 95% confidence intervals for total biomass for the base model (top panel) and a model that includes the 400-mesh eastern trawl survey biomass estimates (bottom panel).

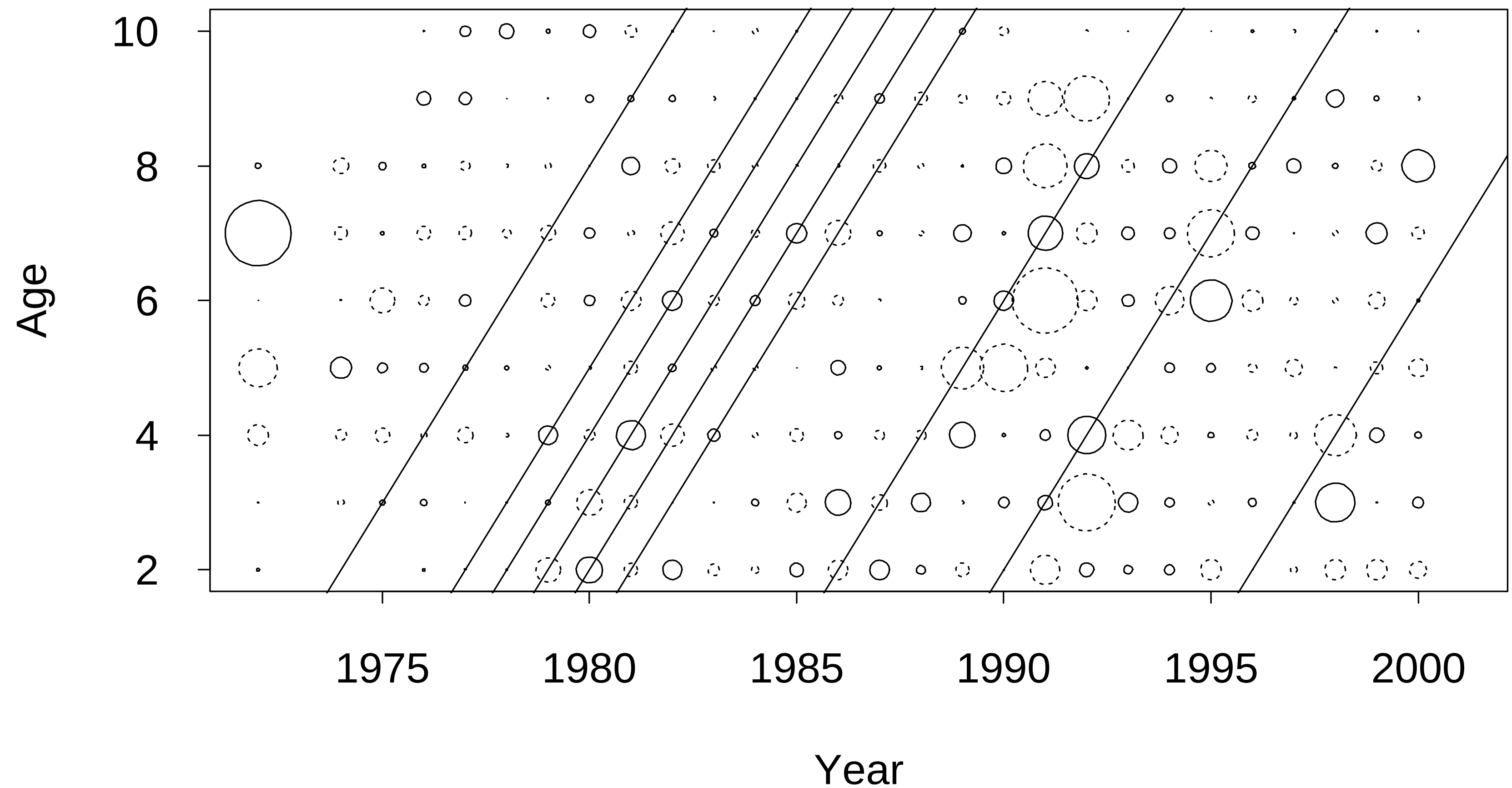


Figure 1.19–Residuals from base-run assessment model for fishery age composition (1972-2000). Circle diameters are proportional to the magnitude of the residual. Circles drawn with dotted lines indicate negative residuals. Diagonal lines show the strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, and 1994).

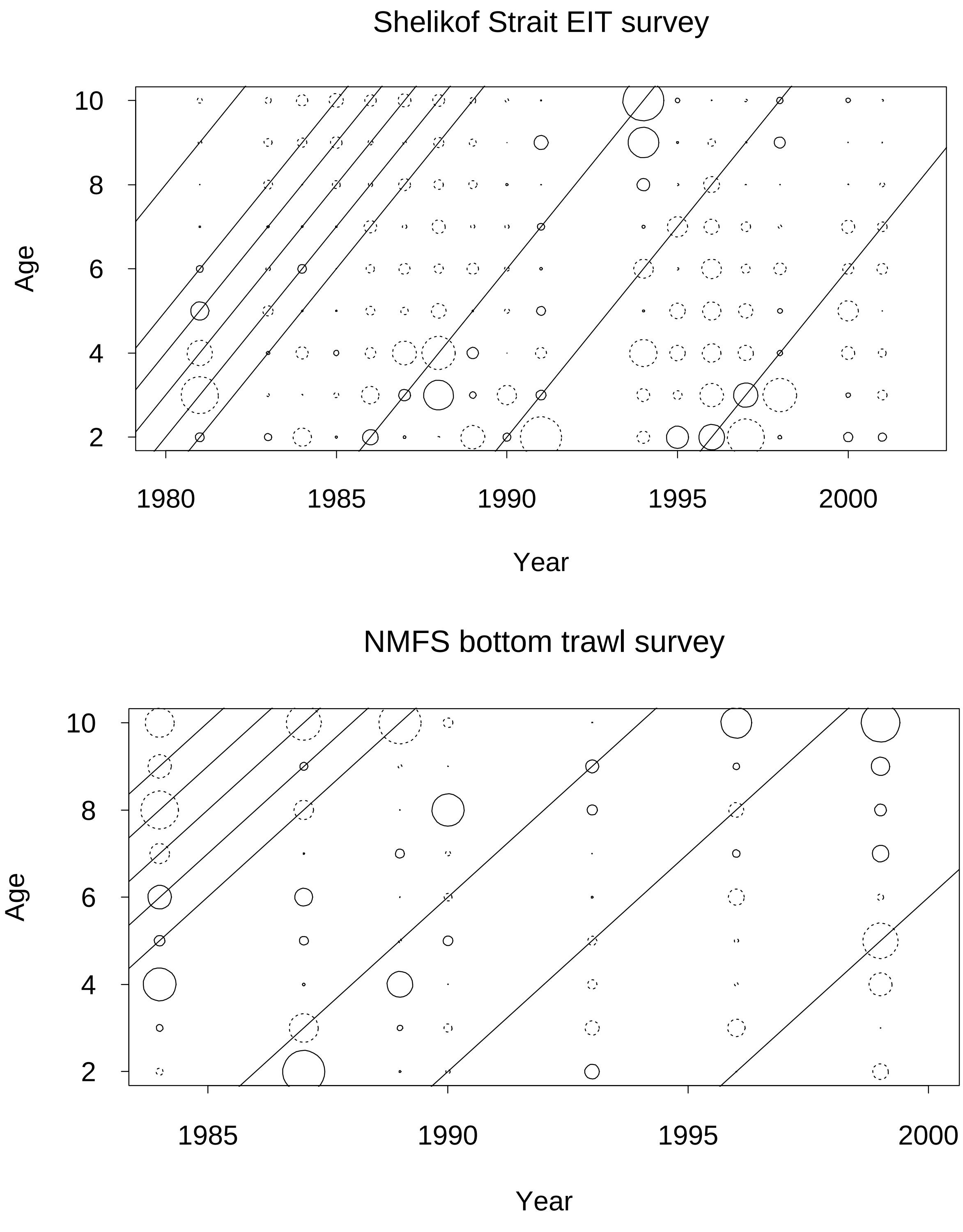


Figure 1.20–Residuals from base-run assessment model for the Shelikof Strait EIT survey age composition (top) and NMFS bottom trawl age composition (bottom). Circle diameters are proportional to the magnitude of the residual. Circles drawn with dotted lines indicate negative residuals. Diagonal lines show the strong year classes (1972, 1975, 1976, 1977, 1978, 1979, 1984, 1988, and 1994).

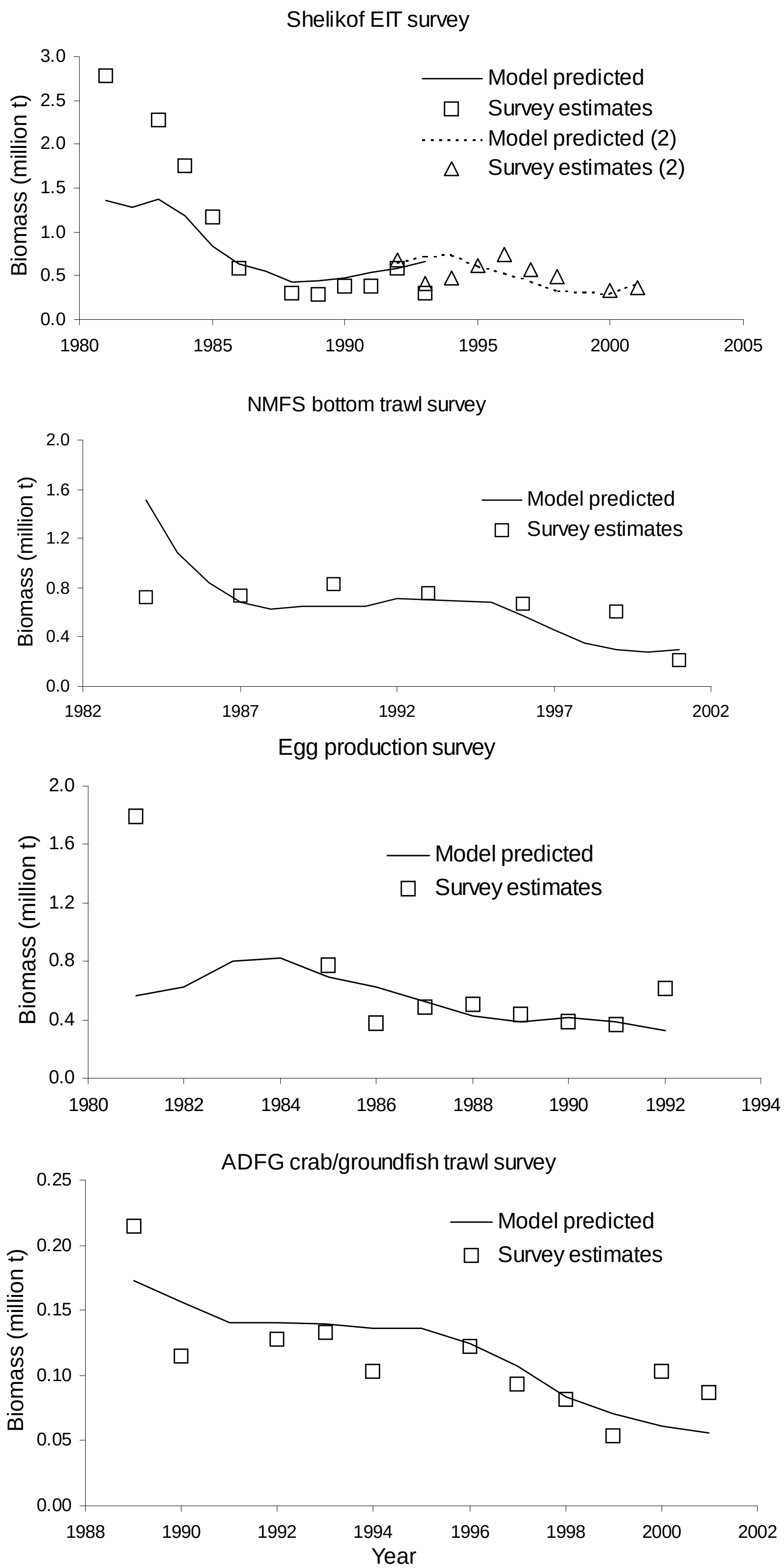


Figure 1.21–Model predicted and observed survey biomass for the Shelikof Strait EIT survey (top panel), NMFS bottom trawl survey (second panel), egg production survey (third panel), and ADFG crab/groundfish survey (bottom panel). The Shelikof EIT survey is modeled with two catchability periods corresponding to the two acoustic systems used for the survey.

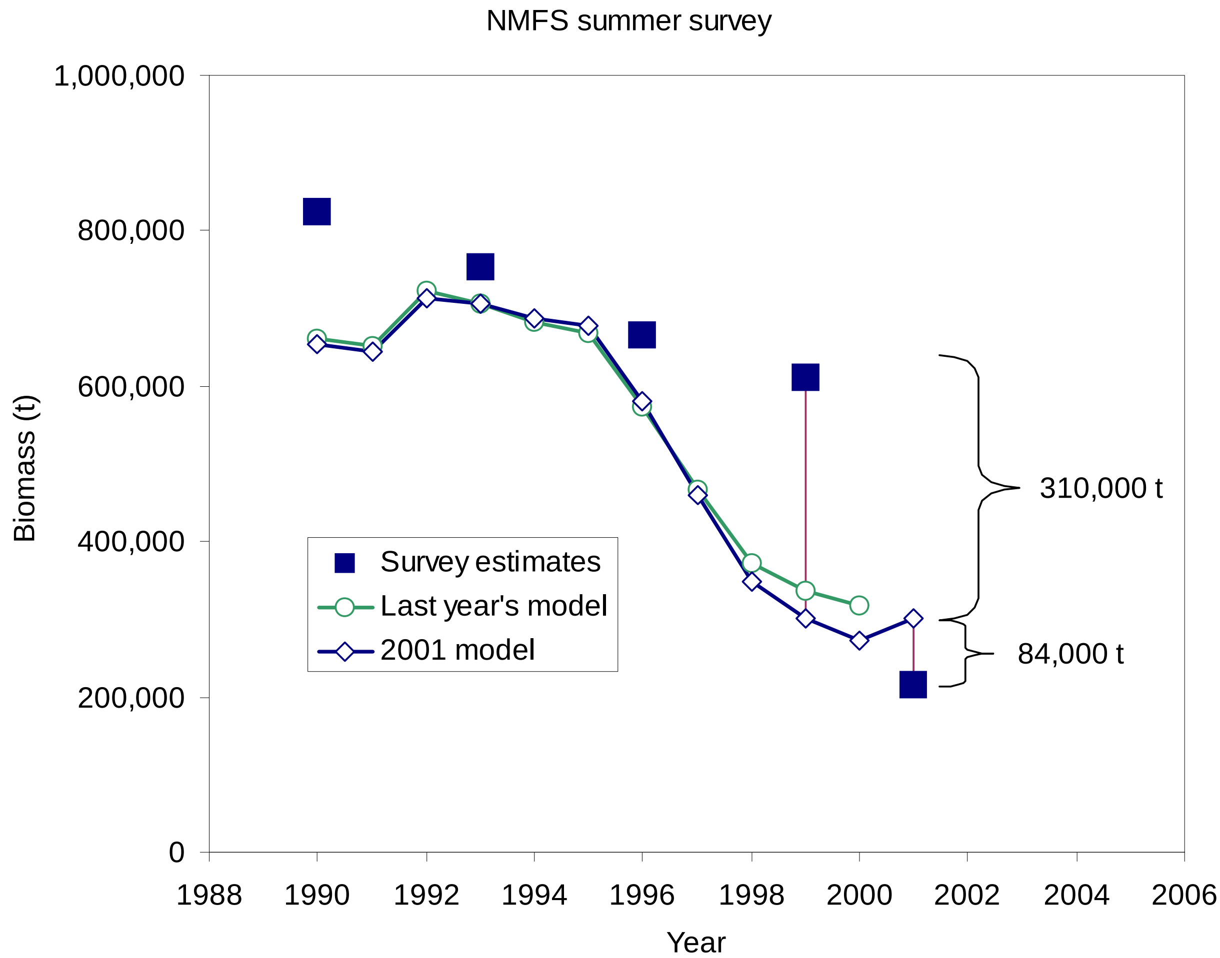


Figure 1.22–Closeup of model fit to the 1999 and 2001 NMFS bottom trawl biomass estimates. The survey CVs of the biomass estimates in 1999 and 2001 are 0.38 and 0.30 respectively.

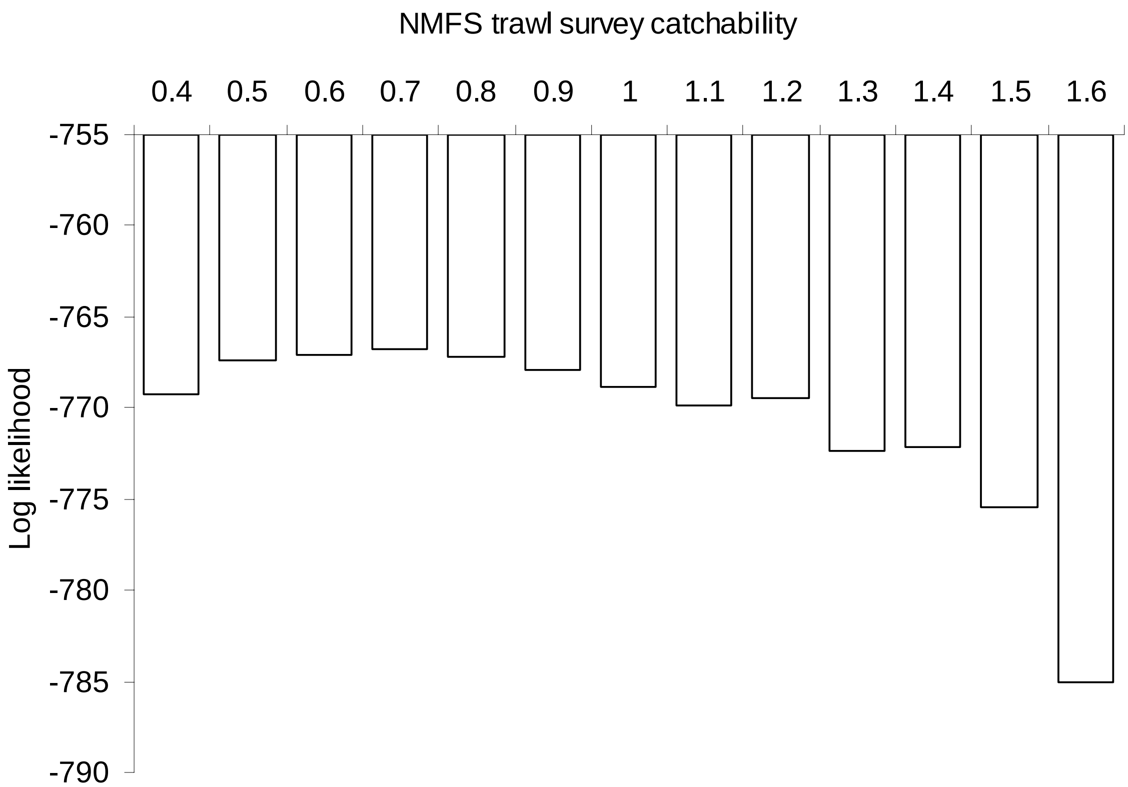


Figure 1.23–Likelihood profile for NMFS trawl survey catchability. The assessment model is based on an assumed catchability of one.

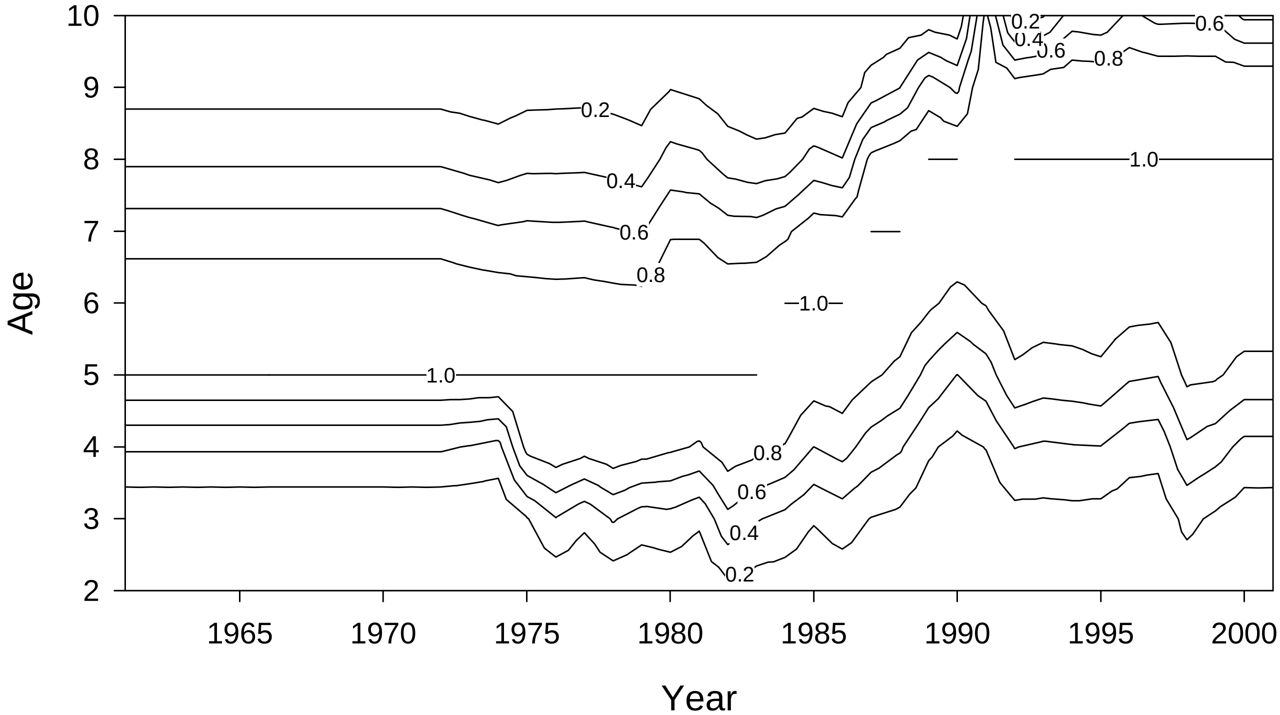
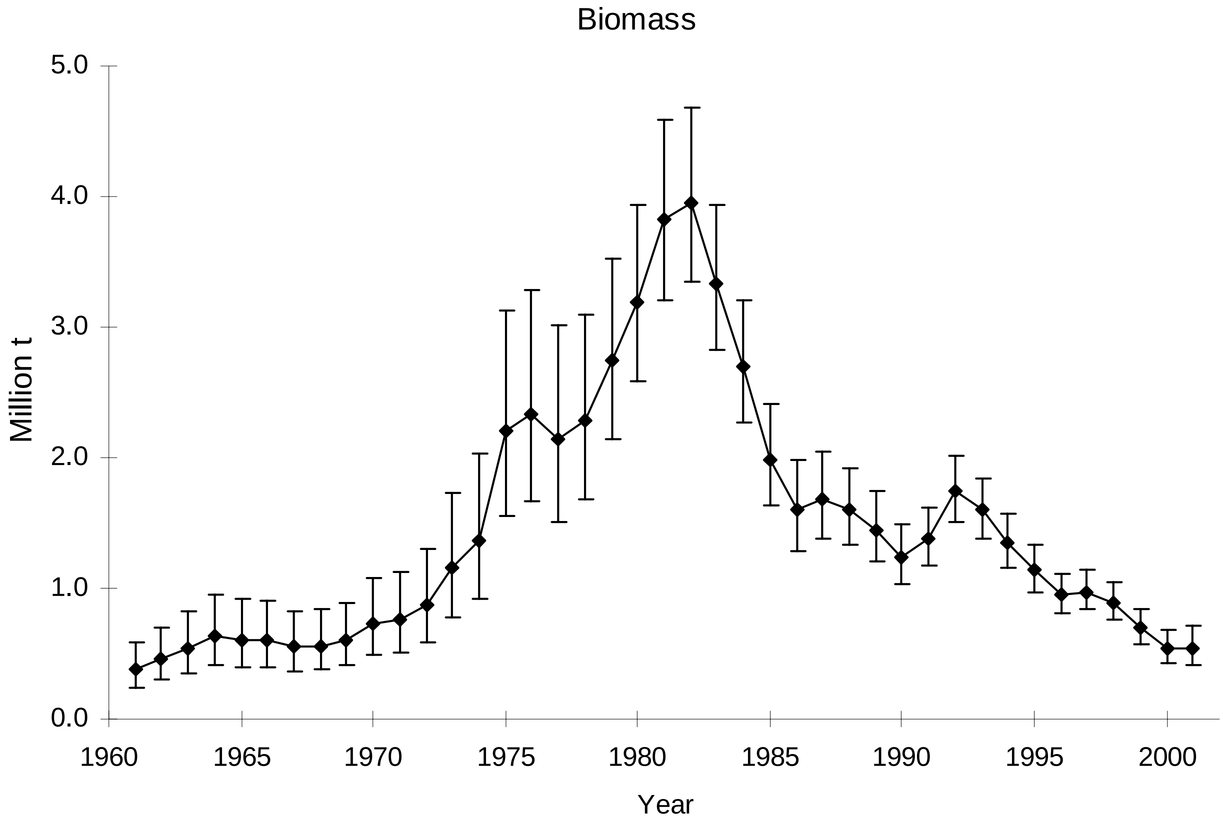


Figure 1.24–Estimates of time-varying fishery selectivity for Gulf of Alaska pollock.



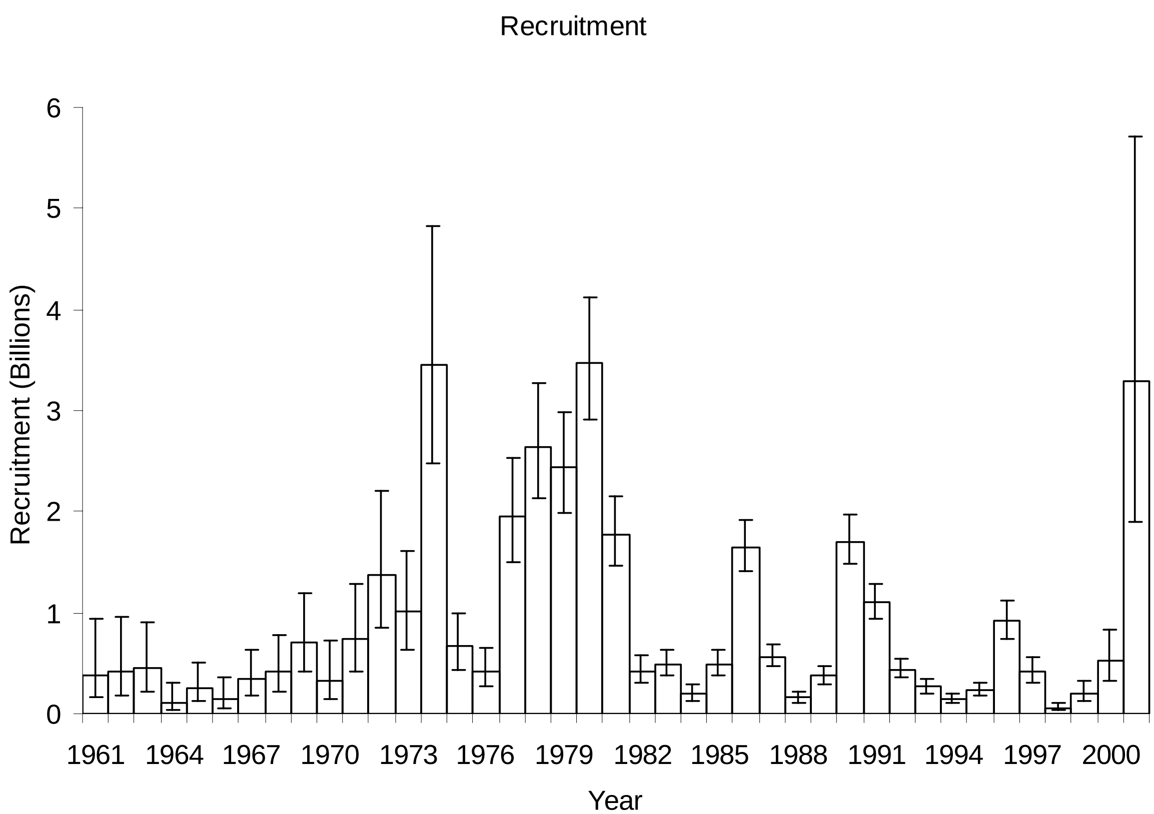


Figure 1.25–Estimated time series of Gulf of Alaska pollock age 3+ biomass (million t) and age-2 recruitment (billions of fish) from1961 to 2001. Vertical bars represent two standard deviations.

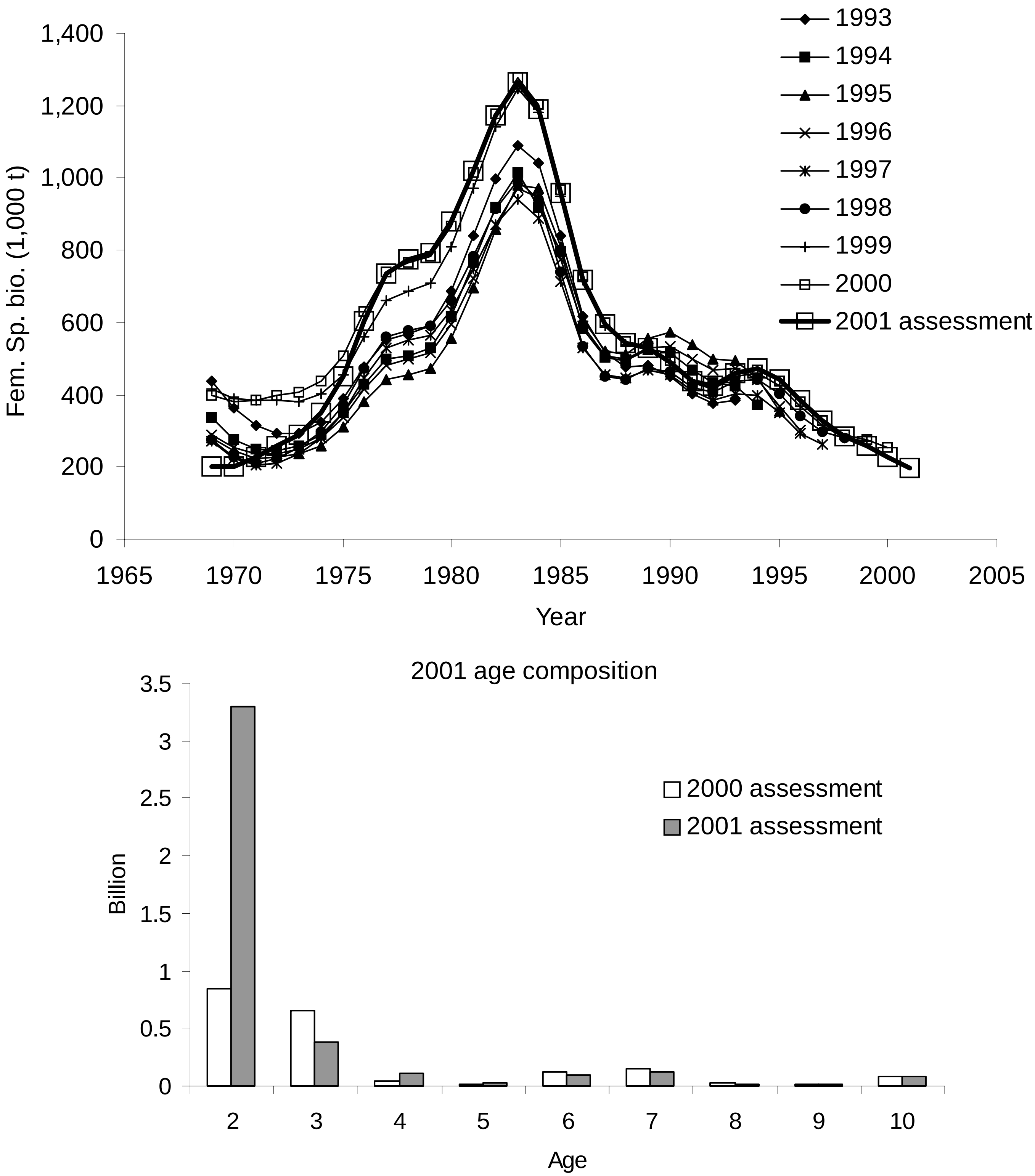


Figure 1.26–Retrospective plot of estimated Gulf of Alaska pollock female spawning biomass for stock assessments in the years 1993-2001 (top panel). For this figure, the time series of female spawning biomass for the 2000 assessment was calculated using the weight at age used in previous assessments to facilitate comparison. The bottom panel shows the estimated age composition in 2001 from the 2000 and 2001 assessments.

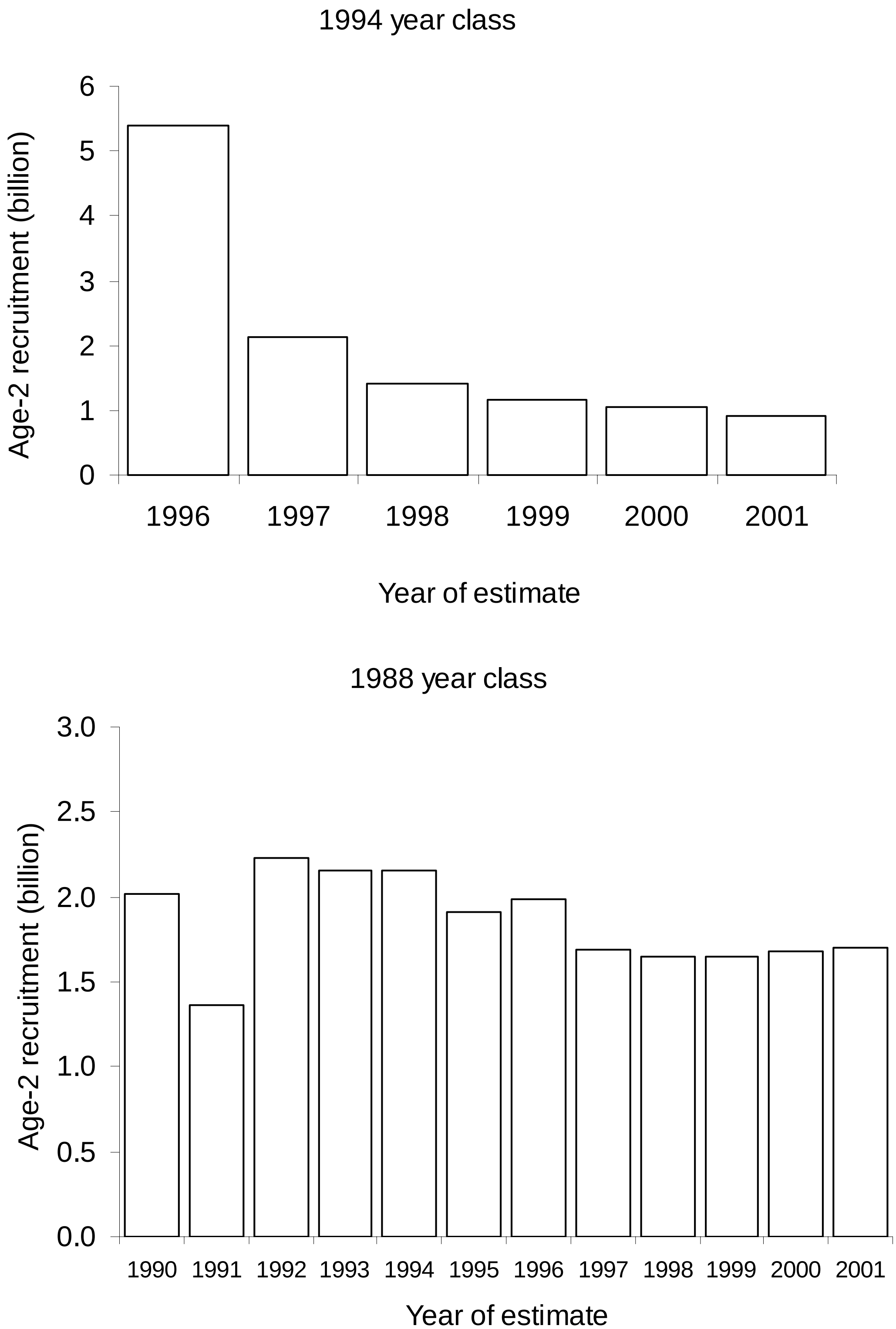


Figure 1.27–Estimates of the 1994 and 1988 year-class strength by assessment year.

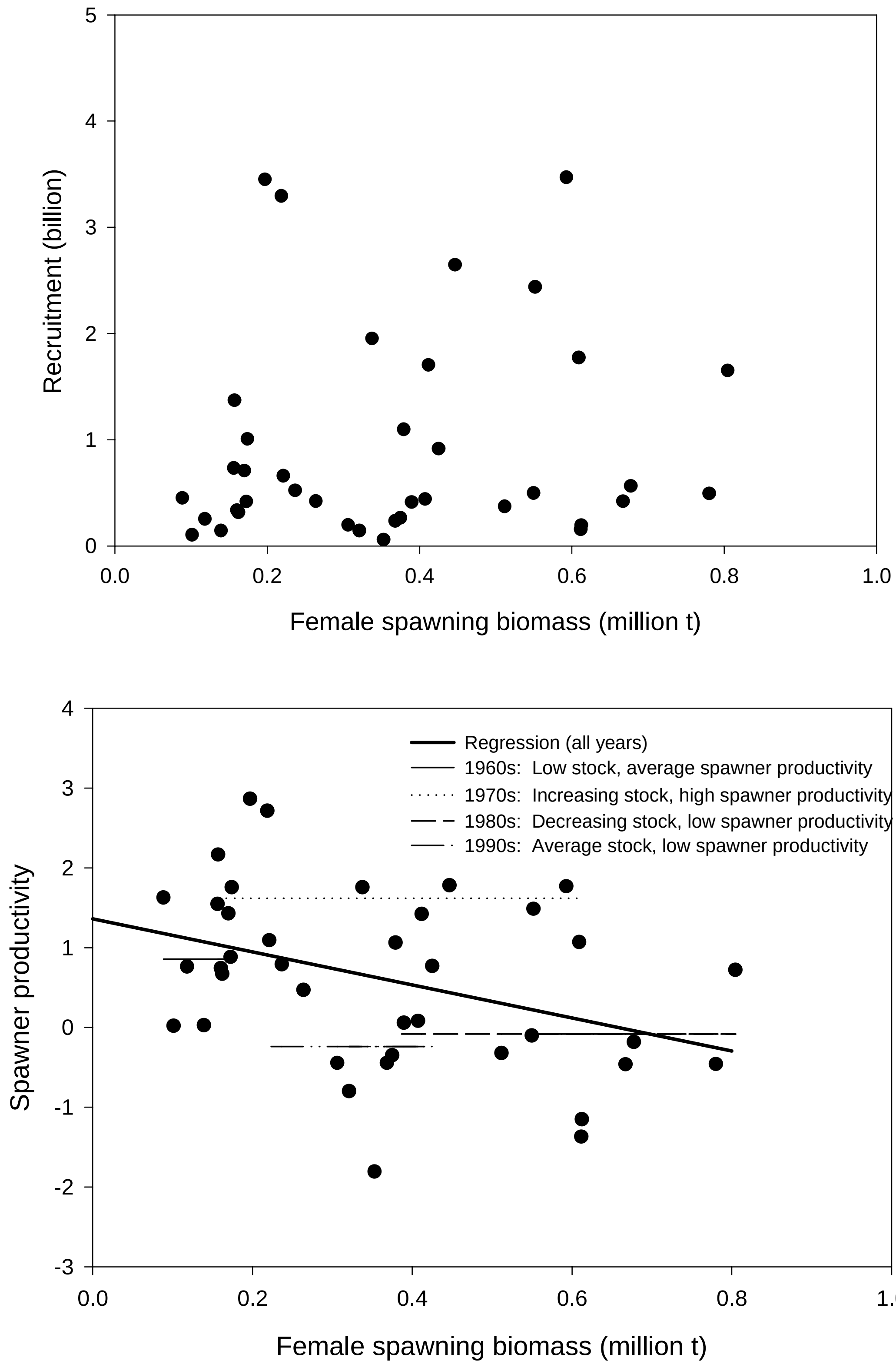


Figure 1.28–Gulf of Alaska pollock recruitment as a function of female spawning biomass (top). Spawner productivity ($\log(R/S)$) in relation to female spawning biomass (bottom). The Ricker stock-recruit curve is linear in a plot of spawner productivity against spawning biomass. Horizontal lines indicate the mean spawner productivity for each decade within the range of spawning biomass indicated by the endpoints of the lines.

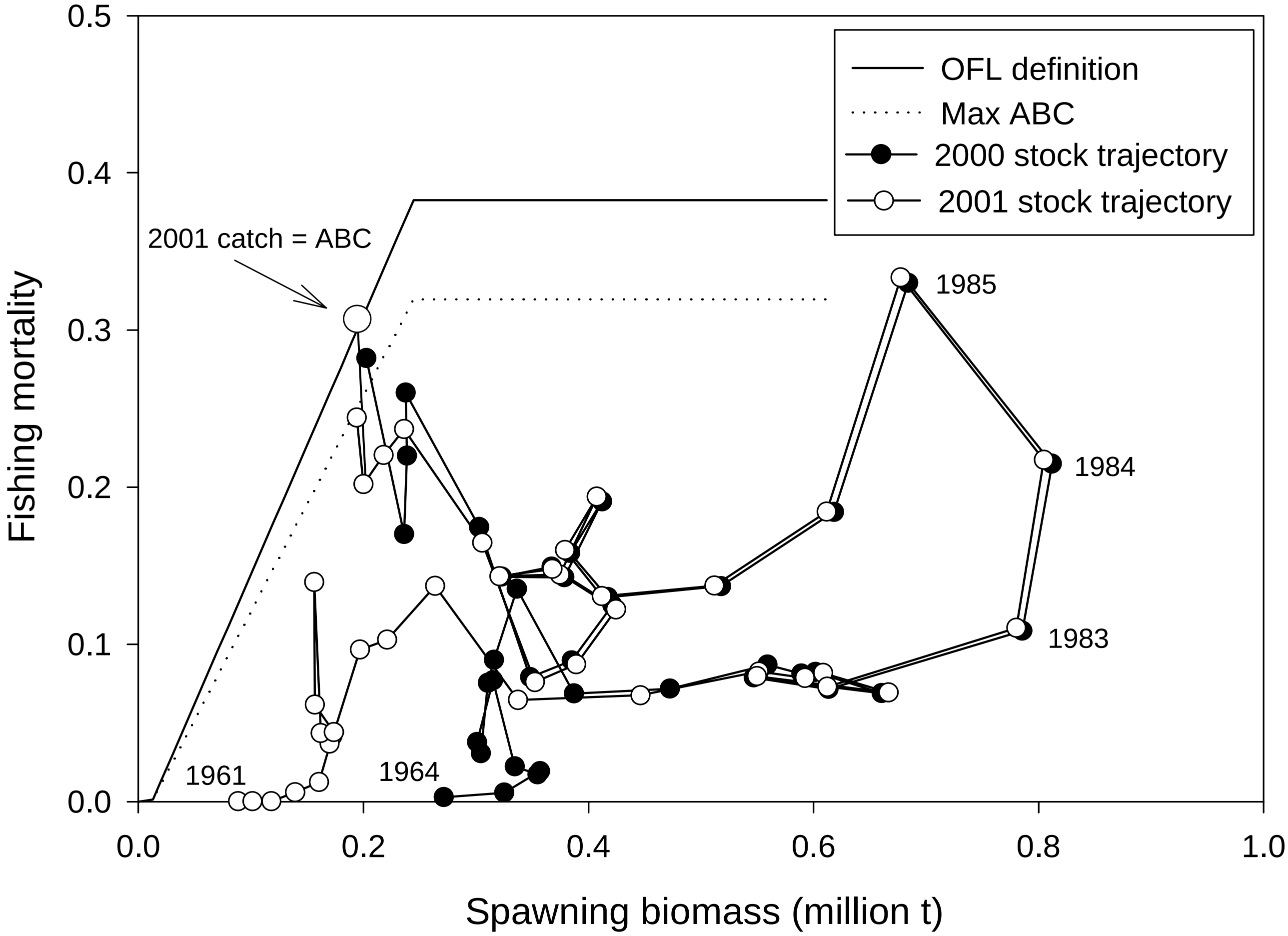


Figure 1.29–Estimates of Gulf of Alaska pollock spawning biomass and fishing mortality (1961-2001) for the current model and last year's model. The OFL definition and maximum permissible ABC are based on current estimates of fishery selectivity, weight at age, and mean recruitment. The endpoints of the lines indicate the unfished spawning biomass of 0.612 million t. For 2001, three points are shown: 1) the projected spawning biomass and fishing mortality from last year's assessment, 2) estimated spawning biomass and fishing mortality from this year's assessment, and 3) the estimated spawning biomass and fishing mortality had last year's ABC been taken.

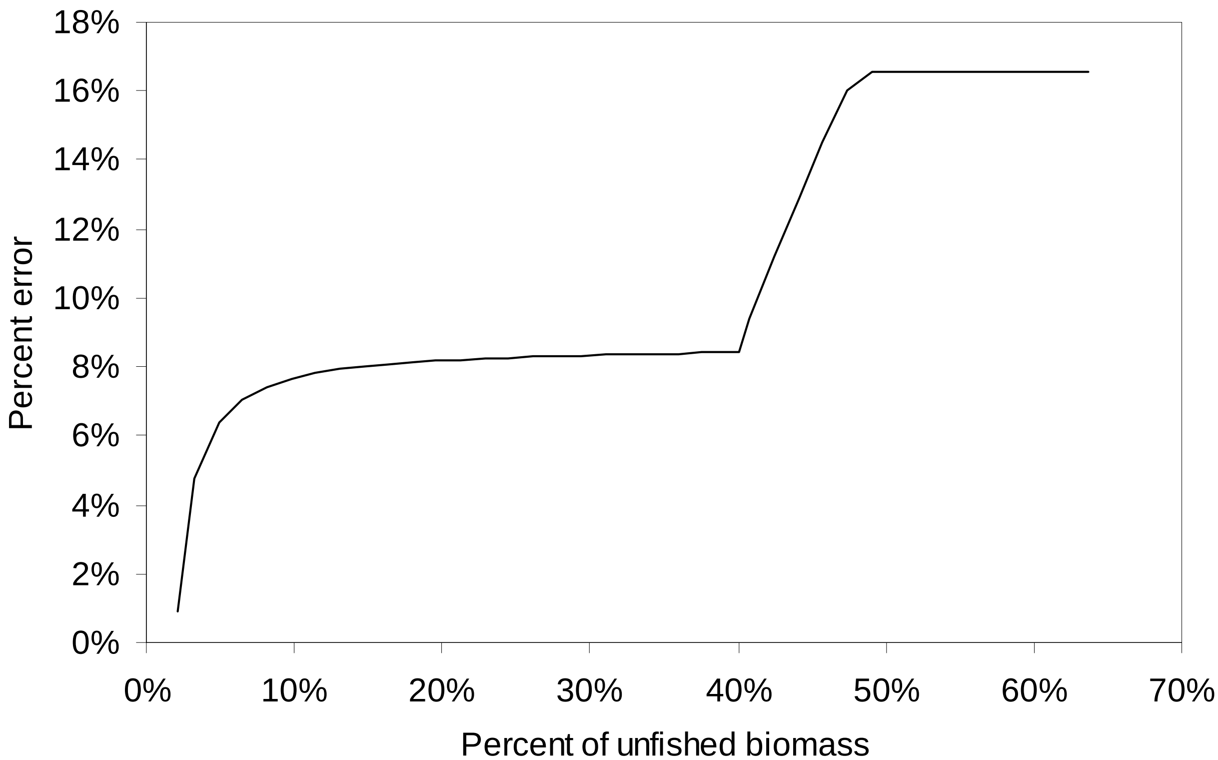


Figure 1.30–Percent error in the estimate of spawning biomass that would result in exceeding the OFL definition when fishing at the maximum permissible F_{ABC} as a function of spawning biomass (as a percent of unfished spawning biomass).

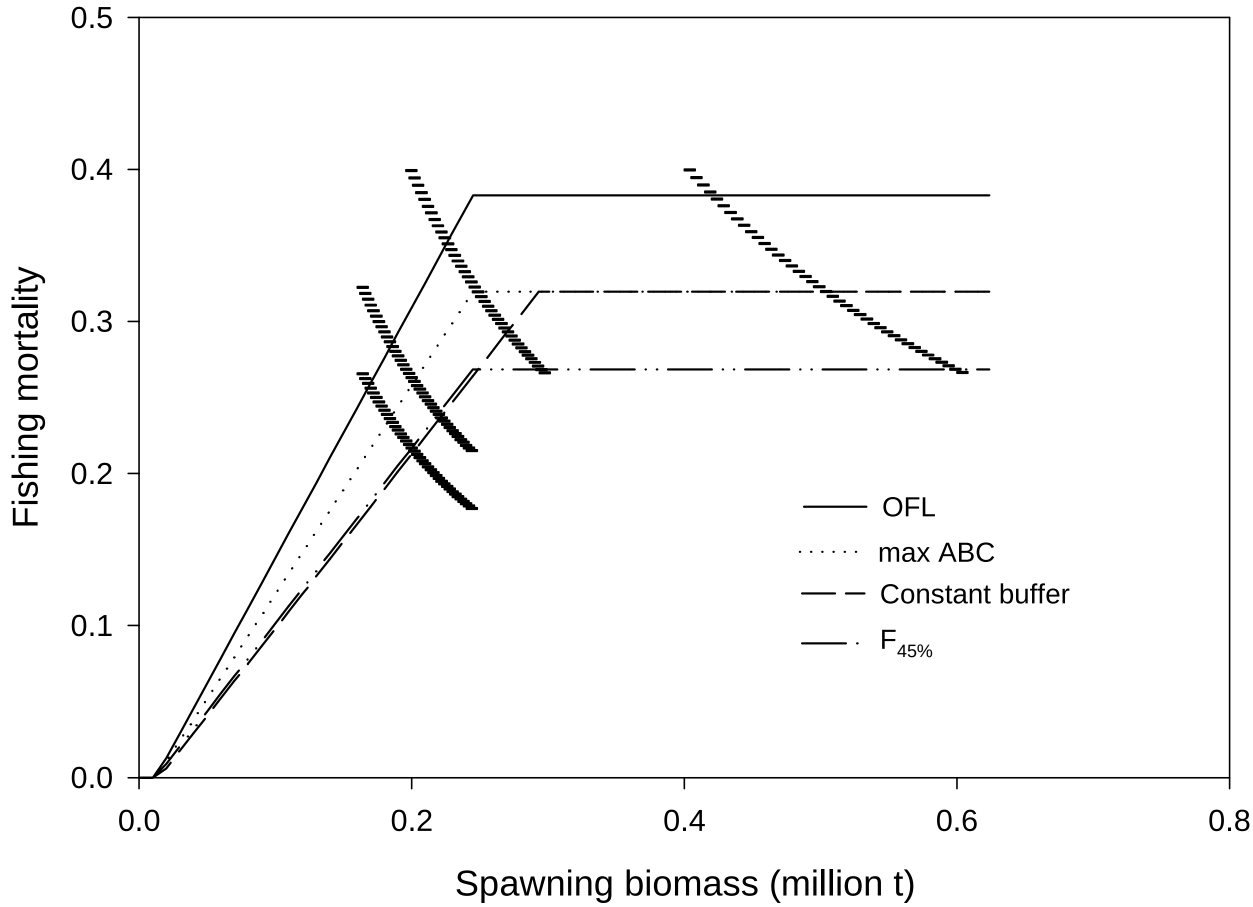


Figure 1.31–Comparison of the F_{OFL} definition, the maximum permissible F_{ABC} , and an $F_{40\%}$ adjusted harvest rate that gives a constant buffer between the OFL and ABC. Tick marks show the effect of plus and minus 20% error in the estimate of spawning biomass ($(B_{true} - \hat{B}) / \hat{B} \times 100$ in increments of 1% when fishing at the maximum permissible F_{ABC}. At 0.2 million tons of spawning biomass, the effect of spawning biomass error is shown for both the maximum permissible F_{ABC} and the $F_{40\%}$ adjusted harvest rate that gives a constant buffer.

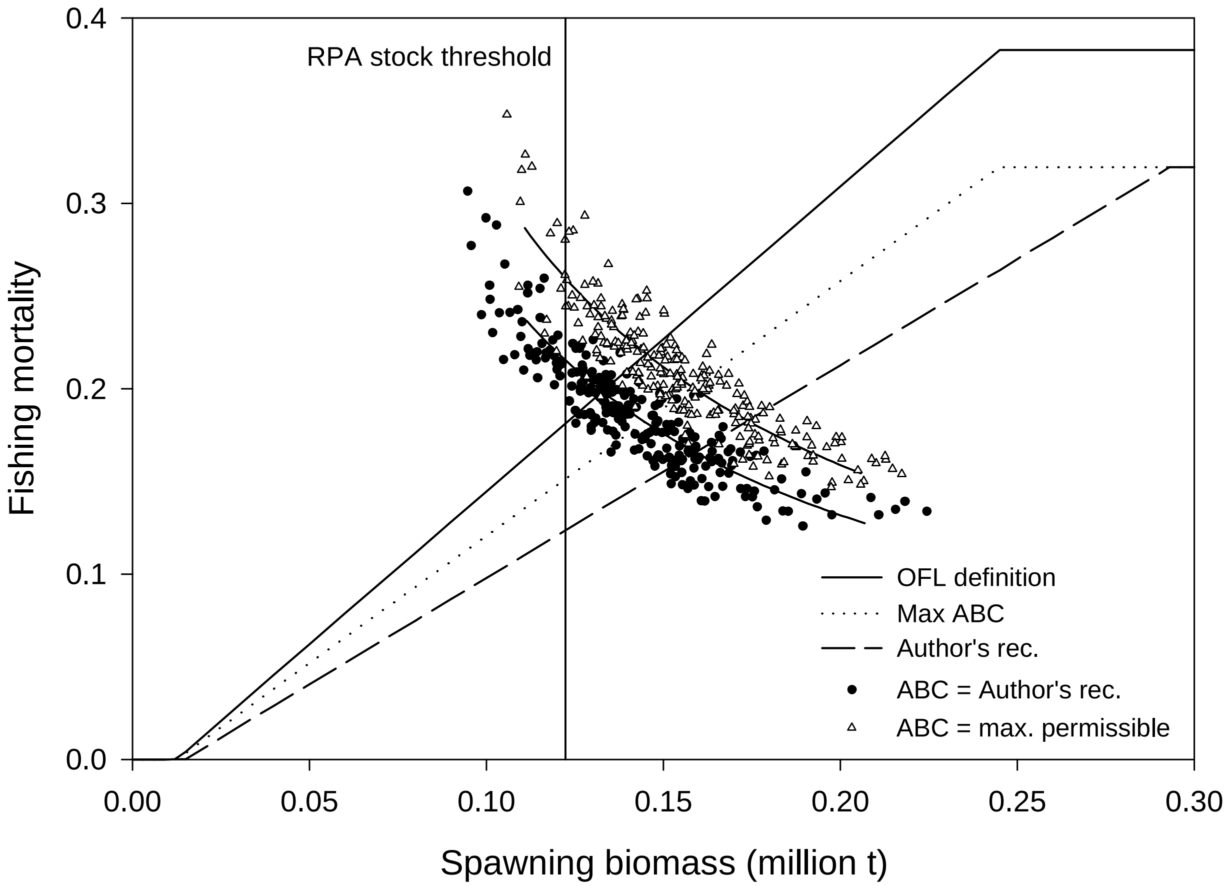


Figure 1.32. Uncertainty in spawning biomass and fishing mortality in 2002 as illustrated by a subsample of 250 from a thinned MCMC chain from the joint marginal likelihood. Also shown are the OFL definition, the maximum permissible ABC and the author's recommended fishing mortality.

Appendix A: Southeast Alaska pollock

Bottom trawl surveys indicate a substantial reduction in pollock abundance east of 140° W. long. Stock structure in this area is poorly understood. Bailey et al. (1999) suggest that pollock metapopulation structure in southeast Alaska is characterized by numerous fiord populations. In the 1996 and 1999 bottom trawl surveys, higher pollock CPUE in southeast Alaska occurred primarily from Cape Ommaney to Dixon Entrance, where the shelf is more extensive. Pollock size composition in the 1993, 1996 and 1999 surveys was dominated by smaller fish (<40 cm) (Martin 1997). These juvenile pollock are unlikely to influence the population dynamics of pollock in the central and western Gulf of Alaska. Ocean currents are generally northward in this area, suggesting that juvenile settlement is a result of spawning further south. Spawning aggregations of pollock have been reported from the northern part of Dixon Entrance (Saunders et al. 1988).

Historically, there has been very little directed fishing for pollock in southeast Alaska (Fritz 1993). During 1991-2000, pollock catch the Southeast and East Yakutat statistical areas averaged 20 t (Table 1.2). The current ban on trawling east of 140° W. long. would preclude the development of a trawl fishery for pollock in Southeast Alaska.

Pollock biomass estimates from the bottom trawl survey are highly variable, in part due to year-to-year differences in survey coverage. The 1996 and 1999 surveys had the most complete coverage of shallow strata in southeast Alaska, and indicate that stock size is approximately 25-75,000 t (Fig. 1.33). We recommend placing southeast Alaska pollock in Tier 5 of NPFMC harvest policy, and basing the ABC and OFL on natural mortality (0.3) and the biomass >30 cm (a proxy for exploitable biomass) for the 1999 survey. Because the NMFS trawl survey in 2001 did not extend to southeast Alaska, no new survey information will be available until 2003. Biomass in southeast Alaska was estimated by splitting survey strata and CPUE data in the Yakutat INPFC area at 140° W. long. and combining the strata east of the line with comparable strata in the Southeastern INPFC area. This gives a **2002 ABC of 6,460 t** (28,709 t * 0.75 M), and a **2002 OFL of 8,613 t** (28,709 t * M). To assist the Council in setting the TAC for this stock, we note that the pollock catch in the Southeast and East Yakutat has never exceeded 100 t during 1991-2000, and was less than 50 t in all but one year.

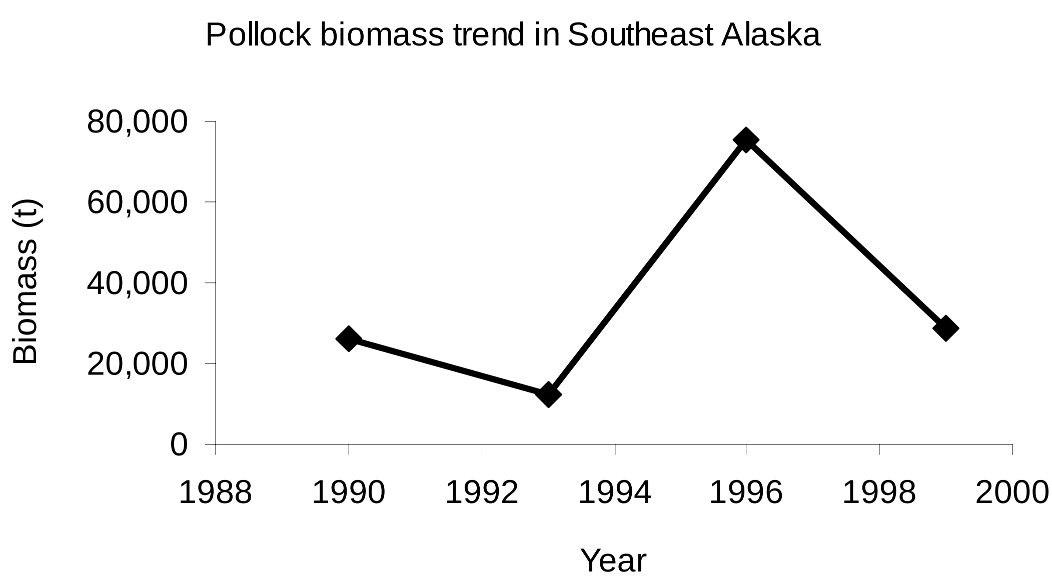


Figure 1.33–Pollock biomass trend in southeast Alaska from triennial surveys in 1990-1999.

Appendix B: Seasonal distribution and apportionment of walleye pollock among management areas in the Gulf of Alaska

Since 1992, the Gulf of Alaska pollock TAC has been apportioned between management areas based on the distribution of biomass in groundfish surveys. Both single species and ecosystem considerations provide the rationale for TAC apportioning. From an ecosystem perspective, apportioning the TAC will spatially distribute the effects of fishing on other pollock consumers (i.e., Steller sea lions), thus reducing the overall intensity of any averse effects. From the perspective of the pollock population, apportioning the TAC ensures that no smaller component of the stock experiences higher mortality than any other. Although no sub-stock units of pollock have yet been identified in the Gulf of Alaska, it would be precautionary to manage the fishery so that if these sub-units do exist they would not be subject to high fishing mortality. Protection of sub-stock units would be most important during spawning season, when they are spatially separated.

The results of genetics studies of stock structure in the Gulf of Alaska have been equivocal. Seeb et al. (in press) did not find differences at two microsatellite loci between spawning populations at Shelikof Strait and Prince William Sound (in press). However a latter collection at Prince William Sound was found to be significantly different than the earlier Prince William Sound collection (Seeb et al. In press). The time of peak spawning is different for each major spawning aggregation in the Gulf of Alaska. In the Shumagin Island area, peak spawning occurs between February 15- March 1, while in Shelikof Strait peak spawning occurs between March 15 and April 1. It is unclear whether this difference in timing is genetic or caused by differing environmental conditions in the two areas. More critically, we simply do not know whether these distinct spawning aggregations are demographically independent sub-populations.

The 2001 Reasonable and Prudent Alternative for the Gulf of Alaska Fisheries Management Plan requires apportionment of pollock TAC based on the seasonal distribution of biomass. Although spatial apportionment is intended to reduce the potential impact of fishing on endangered Steller sea lions, it is important to recognize that apportioning the TAC based on an inaccurate or inappropriate estimate of biomass distribution could have adverse impacts, both on pollock population itself, and on species that depend on pollock for food. For example, before 1999 the apportionment for Kodiak management area (630) during winter was been based on the distribution of pollock in the summer NMFS bottom trawl surveys, when 29% of the biomass on average is found in the Kodiak area (range 18-53%). In results reported later, we estimate that spawning surveys in Shelikof Strait and the Shumagin Islands account for 86% of the total pollock biomass in the Gulf of Alaska. Pollock that spawn on the east side of Kodiak Island may have experienced higher fishing mortality than pollock in the Gulf of Alaska as a whole, increasing (rather than reducing) the likelihood of localized depletion in this area.

Walleye pollock in the Gulf of Alaska undergo an annual migration between summer foraging habitats and winter spawning grounds. Surveys of spawning grounds and surveys during the summer months can be highly variable, indicating either large sampling variability, large interannual changes in distribution, or, more likely, both. Although there is a comprehensive survey of the Gulf of Alaska in summer, surveying during winter has focused on Shelikof Strait, with limited surveying of the Shumagin Islands spawning grounds in the mid-1990s, and some additional exploratory surveying along the shelf break in the early 1990s. It is important to consider how to make best use of limited information on biomass distribution from surveys when apportioning the TAC. Here we summarize available information on 1) the timing of pollock migration to and from spawning areas, 2) the winter distribution of pollock in the Gulf of Alaska, and 3) the summer distribution of pollock

Timing of pollock movement to and from spawning areas

There is limited information concerning the timing of pollock movement to and from spawning areas in the Gulf of Alaska. Replicated surveys of pollock in the 1980s show a gradual buildup of biomass in Shelikof Strait, followed by a rapid decline after the peak of spawning between 15 March and 1 April (Fig. 1.34). Pollock distribution in the Gulf of Alaska trawl survey, which begins in June, shows that pollock have migrated to their summer feeding habitat, with relatively low biomass in areas where spawning occurred earlier in the year, such as upper Shelikof Strait . Since approximately 65% of GOA pollock spawn in Shelikof Strait, there would have to be significant migration of adult fish to the southwest towards the Shumagin Islands and to the east side of Kodiak Island after spawning to achieve the pollock distribution in summer surveys.

Since the earliest survey in Shelikof Strait began on February 21, no information exists on pollock distribution between January 20, when the A season fishery opens, and late February. Anecdotal reports from fisherman suggest that by January 20 pollock have already begun to move into the Shelikof Strait area in preparation for spawning, but corroborating evidence from surveys is lacking.

Winter distribution

In winter, an annual acoustic survey in Shelikof Strait has been conducted since 1981. A significant portion of the remaining shelf and upper slope waters in the Gulf of Alaska west of Cape Suckling has been surveyed at least once during winter by exploratory surveys and surveys with shorter time series. No acoustic survey has been comprehensive, covering all areas where pollock could potentially occur. Therefore a “composite” approach was developed to use data from several different surveys. We used data from 1) Shelikof Strait surveys in 1992-2001, 2) survey of the Shumagin Island area in 1995 and 2001 (Wilson et al. 1995, Guttormsen et al. 2001), and 3) an exploratory survey along the shelf break in 1990 (Karp 1990). Each of these surveys covered a non-overlapping portion of the Gulf of Alaska shelf and upper slope west of Cape Suckling. Surveys of the Shumagin Island area in 1994 and 1996 were not used in this analysis because most fish were in post-spawning condition, and replicated surveys of spawning pollock in Shelikof Strait indicate a rapid decline in abundance after peak spawning (Wilson 1994, Wilson et al. 1996).

The “composite” approach was to estimate the percent of the total stock surveyed during a particular survey by dividing the survey biomass by the estimated total biomass of pollock at spawning from the assessment model (Dorn et al. 1999). The percent for each non-overlapping survey was added together to form a composite biomass distribution, which, with some luck, ought to be close to 100%. Model estimates of biomass at spawning took into account the total mortality between the start of the year and spawning, and used mean weight at age from Shelikof Strait surveys in 1992-2001.

To partition the survey biomass between management areas, a GIS analysis determined the percent of the area-weighted total acoustic backscatter (Sm) along transects by management area. Acoustic backscatter is proportional to biomass as long as the size distribution of fish is similar. This procedure was applied to Shelikof Strait surveys in 1997,1998, 2000, and 2001 and the 1995 and 2001 surveys in the Shumagin Island area. For the 1990 shelf break survey, biomass estimates were summed for subareas were identified as within a management area

Results indicate that an average of 63% of the pollock biomass was in Shelikof Strait in winter (Appendix table 1). For the Shumagin surveys in 1995 and 2001, 24% of the total stock biomass was surveyed. The sum of the percent biomass for all surveys was 96%, which may reflect sampling variability, interannual variation in spawning location, or differences in echo sounder/integration systems, but also suggests reasonable consistency between the aggregate biomass of pollock surveyed acoustically in winter and the assessment model estimates of abundance. After rescaling, the resulting average biomass distribution was 23.05%, 68.08%, and 8.87% in areas 610, 620, and 630.

Summer distribution

The NMFS bottom trawls is summer survey (typically extending from mid-May to mid-August). Because of large shifts in the distribution of pollock between management areas one survey to the next, and the high variance of biomass estimates by management area, Dorn et al. (1999) recommended that the apportionment of pollock TAC be based upon the four most recent NMFS summer surveys. The four-survey average was updated with 2001 survey results resulting in an average biomass distribution of 45.95%, 22.44%, 29.37%, and 2.25% in areas 610, 620, 630, and 640 (Fig. 1.35).

Example calculation of 2001 Seasonal and Area TAC Apportionments under Alternative 4

Warning: This example is based on hypothetical TAC of 100,000 t.

1) Calculate seasonal apportionments of TAC for the A, B, C, and D seasons at 25 %, 25%, 25%, and 25 % of the annual TAC west of 140° W lon.

A season	0.25 x TAC = 25,000 t
B season	0.25 x TAC = 25,000 t
C season	0.25 x TAC = 25,000 t
D season	0.25 x TAC = 25,000 t

2) Since no information is available on the seasonal distribution of pollock in area 640, use summer biomass distribution for all seasons:

A season	0.0225 x A season TAC = 562 t
B season	0.0225 x B season TAC = 563 t
C season	0.0225 x A season TAC = 562 t
D season	0.0225 x B season TAC = 563 t

3) For the A and B season, the allocation of remaining TAC to areas 610, 620 and 630 is based on the “composite” estimate of biomass distribution:

610	0.2305 * (1 - 0.0225) = 22.53%
620	0.6808 * (1 - 0.0225) = 66.55%
630	0.0887 * (1 - 0.0225) = 8.67%

610	0.2253 x A season TAC = 5,632 t
	0.2253 x B season TAC = 5,633 t
620	0.6655 x A season TAC = 16,637 t
	0.6655 x B season TAC = 16,638 t
630	0.0867 x A season TAC = 2,167 t
	0.0867 x B season TAC = 2,168 t

4) For the C and D seasons, the allocation of remaining TAC to areas 610, 620 and 630 is based upon the most recent four survey average biomass distribution of pollock biomass in summer NMFS surveys.

610	0.4595 x C season TAC = 11,487 t
	0.4595 x D season TAC = 11,488 t
620	0.2244 x C season TAC = 5,610 t
	0.2244 x D season TAC = 5,610 t
630	0.2937 x C season TAC = 7,342 t
	0.2937 x D season TAC = 7,343 t

Appendix Table 1. Estimates of percent pollock in management areas 610-630 during winter EIT surveys in the Gulf of Alaska.

					Percent of biomass by management area			Percent of total biomass		
Survey	Year	Model estimates of total 2+ biomass at spawning	Survey biomass estimate[1]	Percent	Area 610	Area 620	Area 630	Area 610	Area 620	Area 630
Shelikof Strait	1992	1,027,620	681,400	66.3%						
Shelikof Strait	1993	1,141,040	408,200	35.8%						
Shelikof Strait	1994	1,143,030	467,300	40.9%						
Shelikof Strait	1995	951,795	618,300	65.0%						
Shelikof Strait	1996	852,269	745,400	87.5%						
Shelikof Strait	1997	778,359	570,100	73.2%	0.0%	98.8%	1.2%			
Shelikof Strait	1998	647,288	489,900	75.7%	0.0%	97.5%	2.5%			
Shelikof Strait	2000	528,085	334,900	63.4%	0.0%	97.8%	2.2%			
Shelikof Strait	2001	646,484	369,600	57.2%	0.0%	98.3%	1.7%			
Shelikof Strait	Average			62.8%	0.0%	98.1%	1.9%	0.0%	61.6%	1.2%
Shumagin	1995	951,795	290,100	30.5%	90.0%	10.0%	0.0%	27.4%	3.0%	0.0%
Shumagin	2001	646,484	108,791	16.8%	84.8%	15.2%	0.0%			
Shumagin	Average			23.7%	87.4%	12.6%	0.0%	20.7%	3.0%	0.0%
Shelf break/east side Kodiak	1990	1,045,880	96,610	9.2%	14.9%	6.2%	78.9%	1.4%	0.6%	7.3%
Total				95.66%				22.05%	65.12%	8.48%
Rescaled total				100.00%				23.05%	68.08%	8.87%

1. The biomass of age-1 pollock was not included in Shelikof Strait survey biomass in 1995 and 2000.

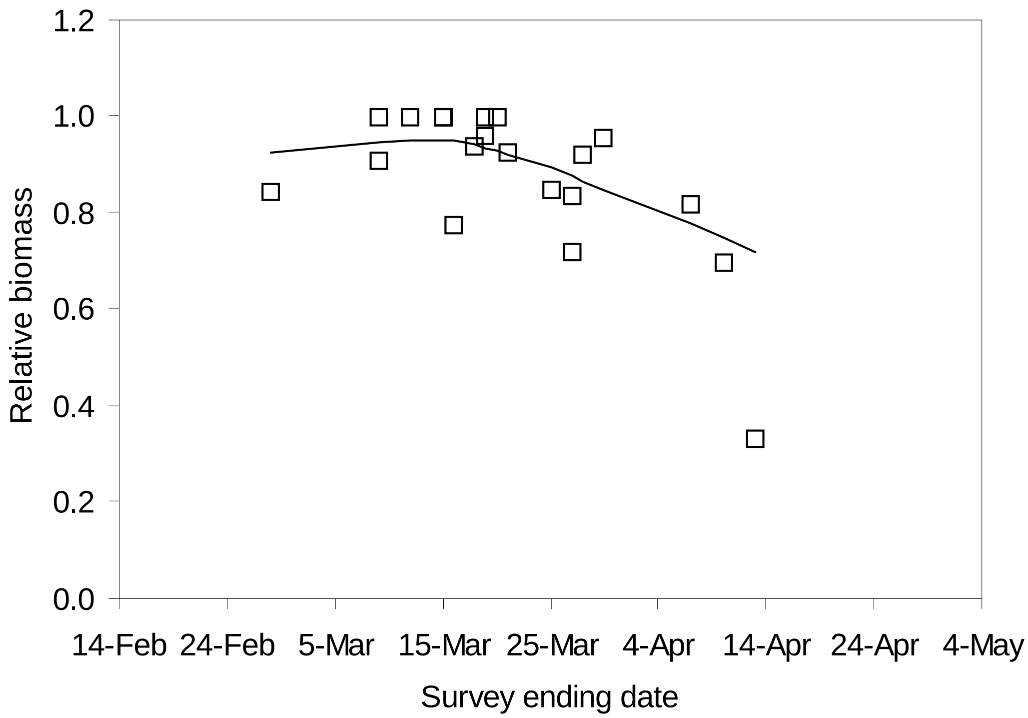
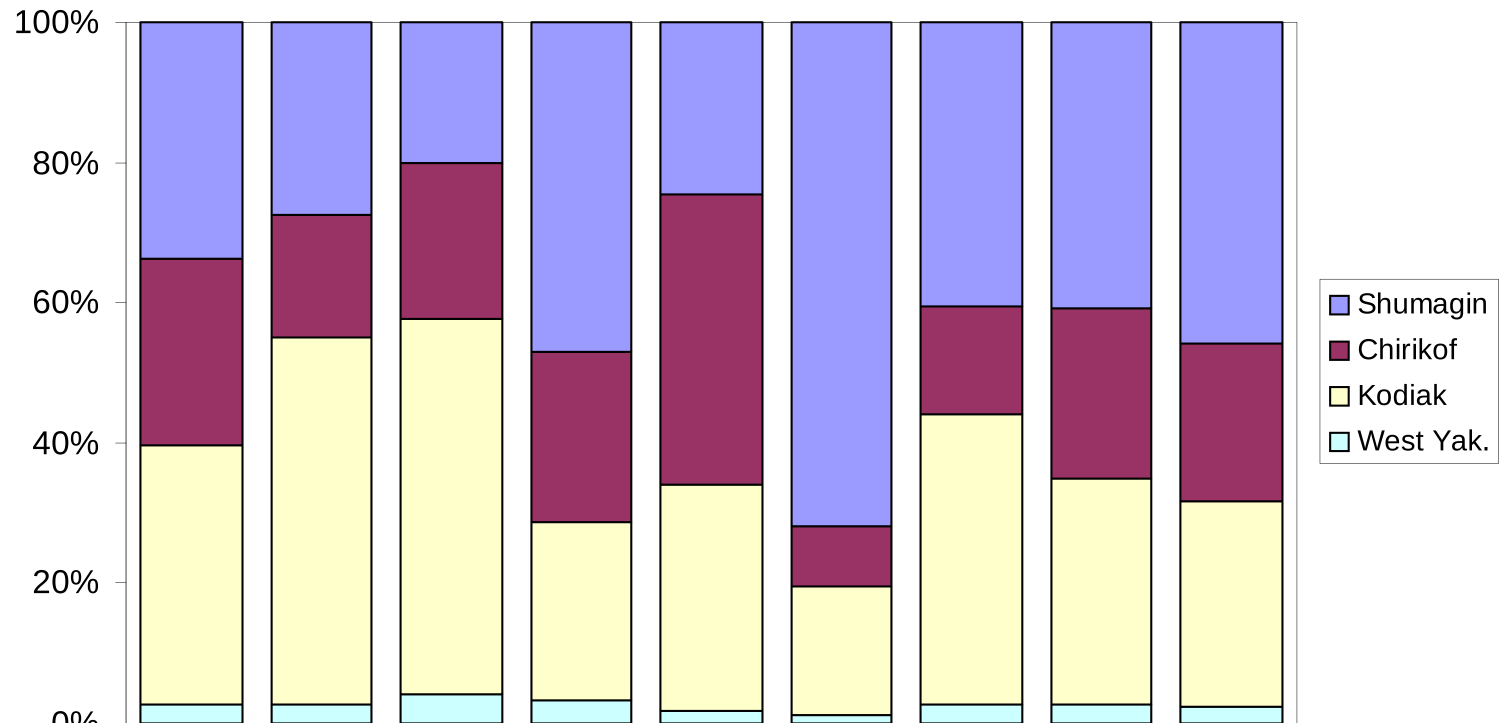


Figure 1.34–Relative biomass of pollock in Shelikof Strait as a function of survey ending date from replicated acoustic surveys in 1981-88. Relative biomass is the survey biomass divided by the maximum survey biomass for the year. A lowess smooth is also shown.



	1984	1987	1990	1993	1996	1999	2001	4 survey avg (1990-99)	4 survey avg (1993-2001)
Shumagin	33.82%	27.59%	20.03%	46.98%	24.60%	71.81%	40.40%	40.85%	45.95%
Chirikof	26.66%	17.38%	22.41%	24.32%	41.37%	8.57%	15.49%	24.17%	22.44%
Kodiak	36.90%	52.41%	53.43%	25.49%	32.20%	18.30%	41.49%	32.36%	29.37%
West Yak.	2.62%	2.62%	4.13%	3.21%	1.83%	1.32%	2.62%	2.62%	2.25%

Figure 1.35–Percent distribution of Gulf of Alaska pollock biomass west of 140° W long in NMFS bottom trawl surveys in 1984-2001. The percent in West Yakutat in 1984, 1987, and 2001 was set equal to the mean percent in 1990-99.

Appendix C: Description of Gulf pollock stock assessment model

Population dynamics: The age-structured model for pollock describes the relationships between population numbers by age and year. The modeled population includes individuals from age 2 to age 10, with age 10 defined as a "plus" group, i.e., all individuals age 10 and older. The model extends from 1964 to 1999 (36 yrs). The Baranov (1918) catch equations are assumed, so that

$$c_{ij} = N_{ij} \frac{F_{ij}}{Z_{ij}} [1 - \exp(-Z_{ij})]$$

$$N_{i+1\ j+1} = N_{ij} \exp(-Z_{ij})$$

$$Z_{ij} = \sum_k F_{ij} + M$$

except for the plus group, where

$$N_{i+1,10} = N_{i,9} \exp(-Z_{i,9}) + N_{i,10} \exp(-Z_{i,10})$$

where N_{ij} = population abundance at the start of year *i* for age *j* fish, F_{ij} = fishing mortality rate in year *i* for age *j* fish, and c_{ij} = catch in year *i* for age *j* fish. A constant natural mortality rate, *M*, irrespective of year and age, is assumed.

Fishing mortality is modeled as a product of year-specific and age-specific factors (Doubleday 1976)

$$F_{ij} = s_j f_i$$

where s_j = age-specific selectivity, and f_i = the annual fishing mortality rate. To ensure that the selectivities are well determined, we require that $\max(s_{jk}) = 1$. Following previous assessments, a scaled double-logistic function (Dorn and Methot 1990) was used to model age-specific selectivity

$$s_j^{/} = \left(\frac{1}{1 + \exp[-\beta_1 (j - \alpha_1)]} \right) \left(1 - \frac{1}{1 + \exp[-\beta_2 (j - \alpha_2)]} \right)$$

$$s_j = s_j^{/} \; / \; \max_j \; (s_j^{/})$$

where α_1 = inflection age, β_1 = slope at the inflection age for the ascending logistic part of the equation, and α_2 , β_2 = the inflection age and slope for the descending logistic part.

Measurement error

Model parameters were estimated by maximum likelihood (Fournier and Archibald 1982, Kimura 1989, 1990, 1991). Fishery observations consist of the total annual catch in tons, C_i, and the proportions at age in the catch, p_{ij} . Predicted values from the model are obtained from

$$\hat{C}_i = \sum_j w_{ij} \; c_{ij}$$

$$\hat{p}_{ij} = c_{ij} \; / \; \sum_j c_{ij}$$

where w_{ij} is the weight at age *j* in year *i* . Year-specific weights at age are used when available.

Log-normal measurement error in total catch and multinomial sampling error in the proportions at age give a log-likelihood of

$$\log \; L_k = -\sum_i [\log(C_i) - \log(\hat{C}_i)]^2 \; / \; 2\sigma_i^2 + \sum_i \; m_i \sum_j \; p_{ij} \; \log(\; \hat{p}_{ij} \; / \; p_{ij})$$

where σ_i is standard deviation of the logarithm of total catch (~ *CV* of total catch) and m_i is the size of the age sample. In the multinomial part of the likelihood, the expected proportions at age have been divided by the observed proportion at age, so that a perfect fit to the data for a year gives a log likelihood value of zero (Fournier and Archibald 1982). This formulation of the likelihood allows considerable flexibility to give different weights (i.e. emphasis) to each estimate of annual catch and age composition. Expressing these weights explicitly as CVs (for the total catch estimates), and sample sizes (for the proportions at age) assists in making reasonable assumptions about appropriate weights for estimates whose variances are not routinely calculated.

Survey observations consist of a total biomass estimate, B_i, and survey proportions at age π_{ij}. Predicted values from the model are obtained from

$$\hat{B}_i = q \sum_j w_{ij} \; s_j \; N_{ij} \; \exp[-\varphi_i \; Z_{ij}]$$

where q = survey catchability, w_{ij} is the survey weight at age *j* in year *i* (if available), s_j = selectivity at age for the survey, and φ_i = fraction of the year to the mid-point of the survey. Although there are multiple surveys for Gulf pollock, a subscript to index a particular survey has been suppressed in the above and subsequent equations in the interest of clarity. Survey selectivity was modeled using a either a double-logistic function of the same form used for fishery selectivity, or simpler variant, such as single logistic function. The expected proportions at age in the survey in the *i*th year are given by

$$\hat{\pi}_{ij} = s_j \; N_{ij} \; \exp[-\varphi_i \; Z_{ij}] \; / \; \sum_j s_j \; N_{ij} \; \exp[-\varphi_i \; Z_{ij}]$$

Log-normal errors in total biomass and multinomial sampling error in the proportions at age give a log-likelihood for survey *k* of

$$\log \; L_k \; = \; -\sum_i \left[\log(B_i) \; - \; \log(\hat{B}_i)\right]^2 \; / \; 2\sigma_i^2 \; + \; \sum_i \; m_i \sum_j \; \pi_{ij} \; \log(\; \hat{\pi}_{ij} \; / \; \pi_{ij})$$

where σ_i is the standard deviation of the logarithm of total biomass (~ CV of the total biomass) and m_i is the size of the age sample from the survey.

Process error

Process error refers to random changes in parameter values from one year to the next. Annual variation in recruitment and fishing mortality can be considered types of process error (Schnute and Richards 1995). In the pollock model, these annual recruitment and fishing mortality parameters are generally estimated as free parameters, with no additional error constraints. We use a process error to describe changes in fisheries selectivity over time. To model temporal variation in a parameter γ , the year-specific value of the parameter is given by

$$\gamma_i \; = \; \overline{\gamma} \; + \; \delta_i$$

where $\overline{\gamma}$ is the mean value (on either a log scale or linear scale), and δ_i is an annual deviation subject to the constraint $\Sigma \; \delta_i \; = \; 0$. For a random walk where annual *changes* are normally distributed, the log-likelihood is

$$\log \; L_{Proc.\;Err.} \; = \; -\sum \frac{(\delta_i \; - \; \delta_{i+1})^2}{2\sigma_i^2}$$

where σ_i is the standard deviation of the annual change in the parameter. We use a process error model for all four parameters of the fishery double-logistic curve.

The total log likelihood is the sum of the likelihood components for each fishery and survey, plus a term for process error,

$$Log \;\; L \; = \; \sum_k \; Log \;\; L_k \; + \; \sum_p \; Log \;\; L_{Proc.\;Err.} \; .$$